

DATA SET CATALOG #147

Jackson's Topside and Bottomside
Reduction Programs

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1. INTRODUCTION:

The documentation for this data set was originally on paper, kept in NSSDC's Data Set Catalogs (DSCs). The paper documentation in the Data Set Catalogs have been made into digital images, and then collected into a single PDF file for each Data Set Catalog. The inventory information in these DSCs is current as of July 1, 2004. This inventory information is now no longer maintained in the DSCs, but is now managed in the inventory part of the NSSDC information system. The information existing in the DSCs is now not needed for locating the data files, but we did not remove that inventory information.

The offline tape datasets have now been migrated from the original magnetic tape to Archival Information Packages (AIP's).

A prior restoration may have been done on data sets, if a requestor of this data set has questions; they should send an inquiry to the request office to see if additional information exists.

2. ERRATA/CHANGE LOG:

NOTE: Changes are made in a text box, and will show up that way when displayed on screen with a PDF reader.

When printing, special settings may be required to make the text box appear on the printed output.

Version	Date	Person	Page	Description of Change
01				
02				

3 LINKS TO RELEVANT INFORMATION IN THE ONLINE NSSDC
INFORMATION SYSTEM:

<http://nssdc.gsfc.nasa.gov/nmc/>

[NOTE: This link will take you to the main page of the NSSDC Master Catalog. There you will be able to perform searches to find additional information]

4. CATALOG MATERIALS:

- a. Associated Documents To find associated documents you will need to know the document ID number and then click here.
<http://nssdcftp.gsfc.nasa.gov/miscellaneous/documents/>

- b. Core Catalog Materials

REQ. AGENT
SAR

RAND NO.
V0319

ACQ. AGENT
DAC

IGRF 1985
INTERNATIONAL GEOMAGNETIC
REFERENCE FIELD DIVISION
MG-14D

This data set catalog consists of one 9-track, 1600 BPI, ASCII magnetic tape. The tape contains 16 files and was created on an IBM 360 computer. The D and C numbers are as follows;

D#
D-71182

C#
C-25271

PROGRAM RSNN

Bottomside N(h) Program

1. Introduction

RSNN is an N(h) reduction program for converting ground based ionosonde data into vertical electron distributions and is stored on the RSRS library exordis PROGRAM RSRS on EDS cartridge 000003. The original version of the program was acquired from Mr. J. E. Jackson, Code 625, NASA, GSFC, Greenbelt, Maryland 20771, U.S.A., and uses the parabolic in log (N) lamination method of analysis (Doupnik and Schmerling, 1965; Jackson, 1971).

This document describes how to (a) prepare the computer input data from N(f) data scaled from ionograms and (b) run the program. Full details on the interpretation and the scaling of the ionograms can be obtained from the "URSI Handbook of Ionogram Interpretation and Reduction" (Piggott and Rawer, 1964) and an extensive treatment of N(h) reduction techniques is given in the special issue of Radio Science, Vol 2, published in September 1967.

2. Brief description of the program

Essentially the program uses the O-trace to calculate a number (specified by the user) of trial N(h) profiles corresponding to different combinations of starting frequency and E-valley depth. A theoretical 'A-trace' is computed for each trial N(h) profile and the standard deviation and average virtual height difference between the observed A-trace and each computed trace are calculated. The N(h) profile which leads to the minimum error is thus the most likely solution.

It should be appreciated, however, that the accuracy of the derived electron distributions depends critically on the quality of the ionogram. It is doubtful, therefore, whether it is worth taking account of the effects of the E-valley

the E-layer dump is poorly defined or if the ionograms can not be sorted to an accuracy of better than 0.1 MHz in frequency and 5 km in virtual height (those recorded on photographic paper, for example).

3. Data input

The program uses free-format data cards containing the following parameters:-

KZN HTN GN GIN (10, 3F0.0)	These two cards remain
KZD GD GID DELF (10, 3F0.0)	in the data deck at all
-----	times and rarely need changing.

For each ionogram	{ TITLE(1) - line 1 (20A4)	
	{ TITLE(2) - line 2 (20A4)	
	{ IYR MO MD ITY DIAT DLONG HT N IP IV XLATA (4I0, 3F0.0, 3I0, F0.0)	
	{ NV LVA RUN VAL START (2I0, 3F0.0)	- Optional (see below)
	{ F(1) HP(1) F(2) HP(2) F(i) HP(i)	{ (100 F0.0) - 0-trace data
	{ : : : : : }	
{ F(j) HP(j) - - - - - F(N) HP(N) }		
{ FXD(1), HPXD(1) - - - - - FXD(i) HPXD(i) }	{ (20 F0.0) - X-trace data. Optional (see below)	
{ : : : : : }		
{ FXD(j), HPXD(j) - - - - - FXD(10) HPXD(10) }		

3.1 Definition of the parameters

Night- time para- meters	{ KZN	Number of trial starting frequencies - usually 8.
	{ HTN	Starting height - usually 150 km.
	{ GN	First trial starting frequency - usually 0.1 MHz.
	{ GIN	Increment by which starting frequency is increased - usually 0.1 MHz.
Daytime para- meters	{ KZD	Number of trial starting frequencies - usually 3.
	{ GD	First trial starting frequency - usually 0.16 MHz
	{ GID	Increment by which starting frequency is increased - usually 0.1 MHz
	{ DELF	Increment by which E-valley depth is increased below f _o E - usually 0.2 MHz.

TITLE (1) Two cards are used for providing a heading to the computed results.

TITLE (2) The first card usually contains a general heading and the second contains a more specific heading relating to each ionogram.

YR Year

MO Month

MD Day

ITI Local standard time (Hrs. Mins. Secs) eg 172430

DLAT Geographic latitude (north positive)

DLONG Geographic longitude (east positive)

HT Starting height. If less than 120 km 'Daytime parameters' assumed for calculating trial $N(h)$ profiles.

N 1 + number of data points scaled from the O-trace.

IP If IP = 0, short version of output printed (see Section 4), otherwise detailed version printed.

IV IV = 1 if valley correction or special run (see below) required, otherwise set IV = 0 in which case the card containing NV etc. should be omitted.

XDATA XDATA = 0.0 if X-trace data are available. Otherwise set XDATA = 1.0 in which case X-trace data cards should be omitted and only one $N(h)$ profile should be computed using the special run facility (see below).

NV 2 + number of data points scaled between f_{min} and foE inclusive.

LVA Number of trial valley depths, i.e. 1 + LVA profiles are computed for each starting frequency with depths of 0, DELF, 2 DELF LVA x DELF MHz.

RUN RUN = 1.0 for special run, in which case VAL and START must be assigned values, otherwise RUN, VAL and START = 0.0

VAL Minimum electron concentration in the E-valley
electron concentration corresponding to foE.

START	[	<u>Starting frequency</u>	]
		f _{0E}	

F(1) HP(1) F(1) = 0.0 always. HP(1) = starting height (HT)

F(2) HP(2) F(2) = f_{min} HP(2) = virtual height of f_{min}

F(3) HP(3) 0-trace frequencies and corresponding virtual heights

⋮ scaled at any frequency interval. It is unnecessary to

F(N) HP(N) scale more than about 25 points.

FXD(1) HPXD(1) X-trace frequencies and corresponding virtual heights.

⋮ Ten points should be scaled, five of which should be

FXD(10) HPXD(10) close to the E-layer cusp on the X-trace.

4. Lineprinter output

Two versions are available; a short version (obtained by setting IP = 0) or a detailed version (obtained by setting IP = 1)

4.1 Contents of the short version

0-trace input data

Standard deviation and average difference between the observed and computed X-traces.

Interpolated electron concentration at intervals of 10^4 electrons cm^{-2} .

Interpolated electron concentration at 10 km height intervals above the E-valley.

Extrapolated values of hmF₂ and NmF₂.

Extrapolated values of electron concentration at 10 km intervals between

$h_f(N)$ and hmF₂.

4.2 Contents of the detailed version

As 4.1 but also including:-

The magnetic dip and gyrofrequency at the starting height.

The electron concentration and gyro frequency at, and the height of, the reflection point of the coded 0-trace frequencies.

The computed X-trace.

A detailed comparison of the observed and computed X-traces.

5. Running the program on the BRSR 1904A computer

The following cards are required.

INPUT :user name, NHDATA

```

_____)
_____)
_____) Data cards
_____)
_____)

```

RUNJOB NHJOB, :user name,RUNBIN,LDERSR BSRH,CORE19000,,CR NHDATA,,LP,-
JOBTIMEmins,TIMEmins

5.1 Time required

The mill time required depends on (a) the number of ionograms, (b) the number of trial $N(h)$ profiles for each ionogram and (c) the number of points scaled from the 0-trace. It takes approximately 30 secs to compute one $N(h)$ profile from 25 data points. Thus 4 ionograms (each with 25 data points) which require 3 trial starting frequencies and 2 trial valley depths would take

$$4 \times 3 \times (1 + 2) \times \frac{30}{60} = 18 \text{ minutes of mill time.}$$

The job time is approximately 10 minutes greater than the mill time.

6. Example

The following example shows the cards required to process one daytime and one night-time ionogram. In the case of the daytime ionogram, three trial starting frequencies and two trial valley depths (0.2 and 0.4 MHz) are used with a detailed printout of the results. In the case of the night-time ionogram, eight trial starting frequencies are used and a short version of the output is requested.

INPUT :ABCHYZ, NHDATA

5 1.0 0.1 0.1

3 0.16 0.1 0.2

WALLOPS ISLAND

DAYTIME IONOGRAM

70 3 7 151900 37.84 -75.47 80.25 1 1 0.

9 2 0.0 0.0.

0.0 80. 1.5 102. 1.75 110. 2.0 112. 2.5 115. }

3.0 125. 3.26 172. 3.32 280. 3.4 248. 3.5 235. }

3.7 232. 3.9 238. 4.1 240. 4.3 248. 4.5 250. }

5.0 255. 5.5 255. 6.0 257. 6.5 262. 7.0 265. }

8.0 280. 9.0 305. 10.0 335. 11.0 385. 11.7 430. }

O-trace data

4.2 275. 4.3 265. 4.4 257. 4.5 255. 4.6 255. }

5.0 262. 5.5 270. 6.0 270. 6.5 270. 7.0 274. }

X-trace data

WALLOPS ISLAND

NIGHT-TIME IONOGRAM

68 4 4 214500 37.84 -75.47 150.15 0 0 0.

0.0 150. 1.16 270. 1.25 270. 1.5 270. 1.75 275. }

2.0 285. 2.5 292. 3.0 305. 3.5 320. 4.0 333. }

4.5 355. 5.0 380. 5.3 400. 5.6 430. 5.8 470. }

O-trace data

1.88 318. 2.0 310. 2.5 298. 3.0 298. 3.9 315. }

4.1 320. 4.3 325. 4.5 330. 4.7 340. 4.9 345. }

X-trace data

RUNJOB NHJOB, : ABCXYZ, RUNBIN, LDRSRS BSNH, CORE19000, CR NHDATA, LP,

JOBTIME15MINS, TIMESMINS

7. References

- Doupnik J. R. and Schmerling E. R. 1965 J. Atmosph. Terr. Phys. 27, 917
- Jackson J. E. 1971 "The $p'(r)$ to $N(h)$ inversion problem in ionospheric soundings" GSFC Report X-625-71-186
- Piggott W. R. and Rawer K. 1961 URSI Handbook of Ionogram Interpretation and Reduction Elsevier, London.

Bottomside $N(h)$ Program1. Introduction

BSMH is an $N(h)$ reduction program for converting ground based ionosonde data into vertical electron distributions and is stored on the RSRS library as file PROGRAM RSRS on EDS cartridge 000003. The original version of the program was acquired from Mr. J. E. Jackson, Code 625, NASA, GSFC, Greenbelt, Maryland 20771, U.S.A., and uses the parabolic in $\log(N)$ lamination method of analysis (Daspnik and Scherling, 1965; Jackson, 1971).

This document describes how to (a) prepare the computer input data from $E'(f)$ data scaled from ionograms and (b) run the program. Full details on the interpretation and the scaling of the ionograms can be obtained from the "UNSI Handbook of Ionogram Interpretation and Reduction" (Piggott and Rawer, 1964) and an extensive treatment of $N(h)$ reduction techniques is given in the special issue of Radio Science, Vol 2, published in September 1967.

2. Brief description of the program

Essentially the program uses the $\bar{X}$ -trace to calculate a number (specified by the user) of trial $N(h)$ profiles corresponding to different combinations of starting frequency and E-valley depth. A theoretical 'X-trace' is computed for each trial $N(h)$ profile and the standard deviation and average virtual height difference between the observed $\bar{X}$ -trace and each computed trace are calculated. The $N(h)$ profile which leads to the minimum error is thus the most likely solution.

It should be emphasized, however, that the accuracy of the derived electron distributions depends critically on the quality of the ionograms. It is doubtful, therefore, whether it is worth taking account of the effects of the frequency

the E-layer cusp is poorly defined or if the ionograms can not be read to an accuracy of better than 0.1 MHz in frequency and 5 km in virtual height (those recorded on photographic paper, for example).

3. Data input

The program uses free-format data cards containing the following parameters:-

NZN HTN GN GIN (10, 3F0.0)

These two cars remain.

KZD GD GID DELF (10, 5FO.0)

in the data deck at all

times and rarely need changing.

(TITLE(1) = line 1 (X0A4)

(TITLE(2) - line 2 (20A.)

(TYR MO VD ITI DIAT DIONG HT N IP IV XDATA (410, 350,0, 310, 80,0)

(NV LVA RUN VAL START (210, 3PG,0)

- Optional (see below)

$$(F(1) \text{ HP}(1) \text{ } F(2) \text{ HP}(2) \text{ } \dots \text{ } F(i) \text{ HP}(i) \text{ } \dots)$$

•

•

•

$$(FXD(1), HPXD(1) \dots FXD(i) HPXD(i))$$

•

•

 $(20 \text{ FO.0}) = \chi\text{-trace data.}$

Options

(see below)

5.1 Definition of the parameters

Night- (KZN Number of trial starting frequencies - usually 8.

para= (HTN Starting height - usually 150 km.

(GN First trial starting frequency - usually 0.1 MHz.

(GIN Increment by which starting frequency is increased - usually 0.1 MHz

(K2D Number of trial starting frequencies - usually 3.

(DELF Increment by which E-valley depth is increased below FoK - usually 0.2 MHz.

TITLE (1) Two cards are used for providing a heading to the computed results.

TITLE (2) The first card usually contains a general heading and the second contains a more specific heading relating to each ionogram.

IYr Year

MO Month

MD Day

ITI Local standard time (Hrs. Mins. Secs) eg 1/24 50

BLAT Geographic latitude (north positive)

DLONG Geographic longitude (east positive)

HT Starting height. If less than 120 km 'Daytime parameters' assumed for calculating trial $N(h)$ profiles.

N 1 + number of data points scaled from the O-trace.

IP If IP = 0, short version of output printed (see Section 4), otherwise detailed version printed.

IV IV = 1 if valley correction or special run (see below) required, otherwise set IV = 0 in which case the card containing NV etc. should be omitted.

XDATA XDATA = 0.0 if X-trace data are available. Otherwise set XDATA = 1.0 in which case X-trace data cards should be omitted and only one $N(h)$ profile should be computed using the special run facility (see below).

NV 2 + number of data points scaled between f_{min} and foE inclusive.

LVA Number of trial valley depths, i.e. 1 + LVA profiles are computed for each starting frequency with depths of 0, DELF, 2 DELF LVA x DELF MHz.

RUN RUN = 1.0 for special run, in which case VAL and START must be assigned values, otherwise RUN, VAL and START = 0.0

VAL Minimum electron concentration in the X-valley
Electron concentration corresponding to foE.

START	[	<u>Starting frequency</u>	]
		foE	

F(1) HP(1) F(1) = 0.0 always. HP(1) = starting height (HT)

F(2) HP(2) F(2) = $f_{\min}$ HP(2) = virtual height of $f_{\min}$

F(3) HP(3) 0-trace frequencies and corresponding virtual heights

⋮ scaled at any frequency interval. It is unnecessary to

F(N) HP(N) scale more than about 25 points.

FXD(1) HPXD(1) X-trace frequencies and corresponding virtual heights.

⋮ Ten points should be scaled, five of which should be

FXD(10) HPXD(10) close to the E-layer cusp on the X-trace.

4. Lineprinter output

Two versions are available; a short version (obtained by setting IP = 0) or a detailed version (obtained by setting IP = 1)

4.1 Contents of the short version

0-trace input data

Standard deviation and average difference between the observed and computed X-traces.

Interpolated electron concentration at intervals of 10^4 electrons cm^{-2} .

Interpolated electron concentration at 10 km height intervals above the E-valley.

Extrapolated values of hmF2 and NmF2.

Extrapolated values of electron concentration at 10 km intervals between $h_{f(N)}$ and hmF2.

4.2 Contents of the detailed version

As 4.1 but also including:-

The magnetic dip and gyrofrequency at the starting height.

The electron concentration and gyro frequency at, and the height of, the reflection point of the coded 0-trace frequencies.

The computed X-trace.

A detailed comparison of the observed and computed X-traces.

5. Running the Program on the RERS 1900A Computer

The following cards are required.

INPUT :user name, NHDATA

```

_____ )
_____ ) Data cards
_____ )
_____ )

```

RUNJOB NHJOB, :user name,RUNBIN,LDKSR5 65NH,CORR19000,,CR NHDATA,,LP,-
JOBTIME=MIN,TIME=MIN

5.1 Time required

The mill time required depends on (a) the number of ionograms, (b) the number of trial $N(h)$ profiles for each ionogram and (c) the number of points scaled from the O-trace. It takes approximately 30 secs to compute one $N(h)$ profile from 25 data points. Thus 4 ionograms (each with 25 data points) which require 3 trial starting frequencies and 2 trial valley depths would take

$$4 \times 3 \times (1 + 2) \times \frac{30}{60} = 18 \text{ minutes of mill time.}$$

The job time is approximately 10 minutes greater than the mill time.

6. Example

The following example shows the cards required to process one daytime and one night-time ionogram. In the case of the daytime ionogram, three trial starting frequencies and two trial valley depths (0.2 and 0.4 MHz) are used with a detailed printout of the results. In the case of the night-time ionogram, eight trial starting frequencies are used and a short version of the output is requested.

INPUT :ABCXYZ, NHDATA

5 150 0.1 0.1

3 0.16 0.1 0.2

WALLOPS ISLAND

DAYTIME IONOGRAM

70 3 7 151900 37.84 -75.47 80.25 1 1 0.

9 2 0.0 0.0.

0.0 80. 1.5 102. 1.75 110. 2.0 112. 2.5 115. }

3.0 125. 3.26 172. 3.32 280. 3.4 248. 3.5 235. }

3.7 232. 3.9 238. 4.1 240. 4.3 248. 4.5 250. }

5.0 255. 5.5 255. 6.0 257. 6.5 262. 7.0 265. }

8.0 280. 9.0 305. 10.0 335. 11.0 385. 11.7 430. }

O-trace data

4.2 275. 4.3 265. 4.4 257. 4.5 255. 4.6 255. }

5.0 262. 5.5 270. 6.0 270. 6.5 270. 7.0 274. }

X-trace data

WALLOPS ISLAND

NIGHT-TIME IONOGRAM

68 4 4 214500 37.84 -75.47 150.15 0 0 0.

0.0 150. 1.16 270. 1.25 270. 1.5 270. 1.75 275. }

2.0 285. 2.5 292. 3.0 305. 3.5 320. 4.0 333. }

4.5 355. 5.0 380. 5.3 400. 5.6 430. 5.8 470. }

O-trace data

1.88 318. 2.0 310. 2.5 298. 3.0 298. 3.9 315. }

4.1 320. 4.3 325. 4.5 330. 4.7 340. 4.9 345. }

X-trace data

RUNJOB NHJOB, : ABCXYZ, RUNBIN, LDRSRS BSNH, CORE19000, CR NHDATA, LP,

JOBTIME18MINS, TIME8MINS

7. References

- | | | |
|------------------------------------|------|---|
| Doupnik J. R. and Schmerling E. R. | 1965 | J. Atmosph. Terr. Phys. <u>27</u> , 917 |
| Jackson J. E. | 1971 | "The p'(f) to N(h) inversion problem in ionospheric soundings" GSFC Report X-625-71-186 |
| Piggott W. R. and Rawer K. | 1961 | URSI Handbook of Ionogram Interpretation and Reduction Elsevier, London. |

UNITED STATES GOVERNMENT

Memorandum

REPLACED BY
NEW DOCUMENTATION

DATE: 4 May 1971

TO : Mr. Leland Dubach, Code 601
National Space Science Data Center

FROM : Mr. John E. Jackson, Code 625

SUBJECT: Program for the Reduction of Ionograms to Electron Density Profiles.

As you know, I have been requested to provide the National Space Science Data Center with my computer programs for the reduction of ionograms to electron density profiles. The programs in current use at GSFC are written in FORTRAN IV for the IBM-360-91. These programs have been developed over a period of about 5 years, and although they function quite satisfactorily, they are not particularly neat from a FORTRAN standpoint. Statement numbers tend to be completely random, some FORTRAN statements are probably no longer used, and documentation is incomplete. It has therefore been decided to provide the Data Center with a "cleaned" up and "documented" version of the N(h) program. This project, however, cannot be given very high priority, and it will take a few months to complete it. Since requests for these N(h) programs have already arrived, I am sending at this time some "unpolished" but otherwise quite satisfactory programs, together with computer outputs for sample runs.

I. Basic Topside N(h) Programs

This provides the N(h) profile from the topside X trace. It requires a 94 K memory and it should have a Field G program supplied with it (although one could use an inverse cube routine based upon FH at the satellite). The input data is on cards (no tapes required). The user must provide the satellite position, as determined from a World Map and the X trace virtual range vs. frequency. The output gives an N(h) profile for the scaled points and also at fixed heights. It also gives altitudes at selected fixed densities.

II. Comprehensive Topside N(h) Program

This is not supplied at this time. This program will do the same thing as the basic program and include the following options:

- 1) World Map interpolation,
- 2) calculation of $F_x S$ when the start of the X trace is not defined with sufficient accuracy on ionograms,
- 3) allowance for variable satellite position, and
- 4) calculation of O-trace from $N(h)$ profile.

IV. Documentation

The only documentation available at this time is Jackson's paper in the special June 1969 issue of the IEEE on p. 960. Reprints are being sent to the Data Center for distribution with its topside $N(h)$ program.

IV. Program for the Analysis of Ground-Based Soundings

This provides the $N(h)$ profile from the O-trace. The X trace is computed for various starts and E-valleys (day-time ionograms) and compared with observed X trace.

Input on cards include sounder position and O trace virtual heights versus frequency. The required computer memory is 100 K. (No tapes are required)

The program calls for Field G but again this is not essential. Another subroutine required is TAB which has also been supplied to the Data Center.

There is no documentation available at this time.

You may if you wish quote this memorandum (or send a copy of it) to the recipients of my $N(h)$ programs. Additional information will be sent to you as it becomes available.

J. E. Jackson

J. E. Jackson

X-625-71-186

PREPRINT

**THE $P'(f)$ TO $N(h)$ INVERSION PROBLEM
IN IONOSPHERIC SOUNDINGS**

JOHN E. JACKSON

MAY 1971



— GODDARD SPACE FLIGHT CENTER —
GREENBELT, MARYLAND

THE $P'(f)$ TO $N(h)$ INVERSION PROBLEM IN IONOSPHERIC SOUNDINGS

by

John E. Jackson

Laboratory for Planetary Atmospheres
NASA Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

A general review is given of the inversion techniques which are used to derive the ionospheric electron density N as a function of altitude h from group path P' versus frequency f measurements obtained by vertical incidence ionospheric sounders. The paper discusses the medium under investigation, the experimental techniques used to obtain the $P'(f)$ data, the theoretical considerations which lead to the integral equation relating $P'(f)$ to $N(h)$, and the assumptions made in the inversion process. The lamination inversion technique is then presented, with special attention given to mathematical difficulties arising from discontinuities in the $P'(f)$ function, infinities in the integrand, and in some cases unknown integration limits. Methods outlined for minimizing the uncertainties due to discontinuities include the use of redundant information (i.e. the two distinct $P'(f)$ functions available for a given $N(h)$ profile) and the use of models based upon statistical data. Mathematical procedures are

discussed which increase significantly the efficiency and accuracy of the required numerical integrations. Also included are recent refinements in inversion techniques which require fewer assumptions than are made in routine inversion. A number of examples are given to illustrate some of the procedures mentioned and also to point out their limitations. The accuracy of the inversion technique is deduced by comparing the resulting $N(h)$ profile with $N(h)$ data obtained by simultaneous but independent observations.

THE $P'(f)$ TO $N(h)$ INVERSION PROBLEM IN IONOSPHERIC SOUNDINGS

by

J. E. JACKSON

INTRODUCTION

Ionospheric data obtained by the vertical incidence pulse sounding technique have been used extensively to derive profiles of electron density N versus altitude h . The calculation of $N(h)$ profiles from the $P'(f)$ sounder data requires the inversion of an integral equation of the form:

$$P'(f) = \int_{p_0}^{p_r(f)} n' \left[N(p), f, B(p), \Phi(p) \right] dp \quad (1)$$

where

P' = apparent range

f = frequency

p = propagation path

p_0 = location of sounder

p_r = location of reflection point for frequency f

n' = group refractive index (see next paragraph)

N = electron density

B = amplitude of terrestrial magnetic field vector $\vec{B}$

Φ = angle between $\vec{B}$ and direction of propagation.

The fundamental formula for n' is:

$$n' = n + f \frac{\partial n}{\partial f} \quad (2)$$

where n is the real part of the refractive index of the medium. The index n is given by the well-known Appleton-Hartree formula, namely,

$$n^2 = 1 - \frac{2X(1-X)}{2(1-X) - Y_T^2 \pm \sqrt{Y_T^4 + 4(1-X)^2 Y_L^2}} \quad (3)$$

where

$$X = (fN)^2 / f^2 \quad (4)$$

where

$$fN = \text{plasma frequency} = 8.98 \times 10^{-3} \sqrt{N} \quad (5)$$

(fN in MHz; N in electrons/cc

$$Y = fH/f \quad (6)$$

where

$$fH = \text{gyrofrequency} = 2.8B \quad (7)$$

(fH in MHz; B in gauss)

$$Y_T = Y \sin \Phi$$

$$Y_L = Y \cos \Phi$$

$\pm$ = positive sign in front of square root is for the ordinary wave; negative sign is for the extraordinary wave.

The ordinary wave reflects when $X = 1$ (except when $\Phi = 0$) or equivalently (as seen from Eq. 4) when:

$$f = fN \quad (8)$$

The extraordinary wave reflects when $X = 1 - Y$ (if $Y < 1$) and also when $X = 1 + Y$. In $P'(f)$ terminology, however, only the echo corresponding to $X = 1 - Y$ is called an extraordinary echo, and the echo corresponding to $X = 1 + Y$ is called the Z echo. Using Eq. 4 and 6 to express the reflection conditions in terms of fN and fH yields the frequency f_x of the extraordinary echo:

$$f_x = \frac{1}{2}(fH + \sqrt{4fN^2 + fH^2}), \quad (9)$$

and the frequency f_z of the Z echo:

$$f_z = f_x - fH \quad (10)$$

Equation (1) was written in terms of a generalized propagation path p to indicate that the sounder data do not necessarily correspond to "vertical" incidence. The propagation path is, however, essentially a vertical path, if the electron density distribution is only a function of altitude (spherically stratified ionosphere). Most $P'(f)$ to $N(h)$ inversion techniques assume that stratification is essentially spherical within the ionospheric region from which the sounding echoes are received and that the propagation path is vertical. Except when otherwise indicated these assumptions are also made in the present paper, i.e. in Eq. (1) p is replaced by h and Φ is replaced by $(90^\circ - \theta)$ where θ is the magnetic dip angle.

The formulas given above (Eq. 1-10) provide all the information required to evaluate $P'(f)$ for a given $N(p)$, $B(p)$ and $\Phi(p)$. It is seen that these calculations would yield three $P'(f)$ functions since there are three conditions under which reflection can take place. The calculations would require an explicit expression for n' in terms of X , Y_T and Y_L , which is obtained by a straightforward substitution of Eq. (3) into Eq. (2). The resulting formula (see Ref 1 p. 971) is rather complicated and it is not required for the present discussion. The complexity of the n' function makes it impossible to evaluate analytically the integral

shown by Eq. (1), except in very special cases ($\phi = 0$ and $\phi = 90$ degrees). Numerical integration techniques have to be used (even for a very simple $N(h)$ model), and special care must be taken near the reflection points where n' becomes infinite.

It should also be noted that B and ϕ in Eq. (1) are not unknown quantities, since they are specified by the sounder location and can be calculated to a high order of accuracy from a terrestrial field model (Ref 2). Thus the only unknown in the inversion process is $N(h)$, letting $h = p$.

The inversion of Eq. (1) is, to a large extent, performed using the same mathematical techniques as are required for the direct evaluation of Eq. (1). The difficulties encountered in the inversion process are due primarily to gaps and discontinuities in the $P'(f)$ data. The redundancy of the data (availability of more than one $P'(f)$ function) helps overcome these problems. But in many cases it is also necessary to have some knowledge of the gross features of the $N(h)$ distribution.

A complete discussion of the inversion process must therefore include some basic information concerning the medium under investigation and the limitations of the $P'(f)$ measuring technique. The characteristics of the ionosphere and of the sounder technique are such that two sounders (one on the ground and the other in an earth

orbiting satellite) are required to permit a complete determination of the $N(h)$ distribution at a given location. The present paper will discuss the $P'(f)$ to $N(h)$ inversion problems associated with both types of soundings.

THE MEDIUM UNDER INVESTIGATION

Since the ionosphere is produced primarily by ionizing radiation from the sun (offset by subsequent recombination and/or transport of the electron-ion gas thus created), the $N(h)$ distribution depends upon the level of solar activity and experiences diurnal, seasonal, and latitudinal variations. The terrestrial magnetic field influences not only the n' function, but also the $N(h)$ distribution. Both effects are due to the field control (through the $\vec{V} \times \vec{B}$ mechanism) upon the motion (transport or radiowave induced oscillations) of the free electrons. Since the magnetic axis is not aligned with the rotation axis of the earth, the magnetic control produces longitudinal variations in the $N(h)$ distribution (in addition to variations due to local time differences).

Although the variability of the medium can introduce some difficulties (or limitations) in the $N(h)$ calculations, certain features of the daytime and nighttime $N(h)$ distributions are sufficiently regular - at least at midlatitudes - to provide a basis for the conventional division of the ionosphere into

D, E, F1 and F2 regions. The boundaries between these regions have never been precisely defined, but it is usually understood that the D region is below 90 km, the E region between 90 and 140 km, and F1 region between 140 and 180 km, and the F2 region above 180 km. The typical features of the midlatitude $N(h)$ distribution can be seen on Fig. 1, which shows a daytime and a nighttime profile measured over Wallops Island, Virginia. An important characteristic of the distributions is the fact that the electron density becomes significant at an altitude which is about 80 km in the daytime and about 150 km at night (points Q on Fig. 1) and increases almost monotonically up to the height of maximum density ($h_{max}F2$, shown on Fig. 1 as point M) which occurs typically at altitudes between 200 and 400 km. The major exception to this rule occurs in daytime in the region between 110 and 140 km (E valley). Above $h_{max}F2$ (topside ionosphere) the electron density decreases monotonically and very nearly in exponential fashion.

EXPERIMENTAL DETERMINATION OF THE $P'(f)$ FUNCTION

The ionospheric sounder, or ionosonde, operates on principles similar to those of radar, and it provides echoes from the ionosphere over a wide range of operating frequencies. The reflection conditions are such that

- 1) the ionosonde must utilize frequencies lower than

those normally used in radar and 2) a large number of sounding frequencies are required in order to investigate the plasma and obtain its electron density distribution. This last requirement is best met with the swept-frequency system, although single or multiple-fixed frequency sounders are also used for special applications. Ionospheric soundings are typically conducted at frequencies between 0.1 and 20 MHz, using 100 microsecond pulses and a 20-to-60 pulse-per-second repetition rate. A complete frequency sweep takes typically 15 to 30 seconds.

In the widely used swept-frequency system the received echoes are customarily displayed in the "ionogram" format, in which the echo round-trip time Δt is displayed (in the vertical axis direction) as a function of the sounder frequency f . The quantity $(\Delta t)c/2$ (where c = velocity of light in vacuo), which would be the target distance for a conventional radar, is called the apparent range; it represents a distance which is greater than the distance to the echoing region because the sounding signal is retarded by the ionosphere. The apparent range P' at a frequency f_r is therefore:

$$P'(f_r) = \frac{c}{2} (\Delta t_r) \quad (11)$$

where

$$\Delta t_r = 2 \int_{p_0}^{p_r} \frac{dp}{V_g} \quad (12)$$

$V_g = V_g(f, N, B, \Phi)$ = the velocity of the sounding signal,

p_r = a reflection point for the frequency f_r
and the integration is along the path taken by
the wave.

Combining Eqs. (11) and (12) gives

$$P'(f_r) = \int_{p_0}^{p_r} \frac{c}{V_G} dp. \quad (13)$$

In standard magneto-ionic nomenclature, the quantity c/V_G is called the group refractive index n' . Equation (13) then becomes

$$P' = \int_{p_0}^{p_r} n' dp. \quad (14)$$

as given in Eq. (1). The vertical (round-trip) axis of the ionogram is calibrated in terms of the apparent range P' and the basic measurement provided by the ionogram is the apparent range P' as a function of frequency.

CHARACTERISTICS OF TYPICAL $P'(f)$ CURVES

The three reflection conditions (Eqs. 8, 9 and 10) give rise to the ordinary, extraordinary, and Z traces on ionograms. Conventional soundings from the ground rarely yield usable Z traces, but they normally provide both ordinary and extraordinary traces. Each of these $P'(f)$ traces can be used (with appropriate inversion techniques) to derive $N(h)$ profiles. The ordinary trace is generally the most useful one on ground-based soundings and the extraordinary trace is the most useful one on topside soundings (see p. 963 of Ref. 1).

In both cases (topside and ground-based soundings), the presence of at least one trace in addition to the one used for primary data analysis provides redundant information that can be used to check assumptions made in the analysis (i.e. in the inversion of Eq. (1)) and to minimize uncertainties due to gaps in the primary data. Further redundancy of information is also available on topside ionograms, as the result of resonance phenomena which occur at f_N , f_H , and at the upper hybrid frequency f_T , which is given by:

$$f_T = \sqrt{f_N^2 + f_H^2} \quad (15)$$

These resonances permit the calculation of N and B at the satellite, which is particularly helpful when the propagation traces are not clearly defined at the satellite. Since N and B (consequently f_N and f_H) both decrease monotonically with altitude in the topside ionosphere, the $P'(f)$ function is, in principle, known for both ordinary and extraordinary traces for the complete topside profile below the satellite (portion AM of profiles on Fig. 1). On ground-based soundings, however, the $P'(f)$ function is not defined for the portion QR of the profiles on Fig. 1 (where R corresponds to the minimum density for which echoes are obtained by the sounder), and for the portion ST of the daytime profile on Fig. 1.

The ordinary ray $P'(f)$ functions corresponding to $N(h)$ profiles of Fig. 1 are shown on Figs. 2 and 3 for

topside and for ground-based soundings. To permit a direct comparison between apparent heights P' and the actual reflection heights, the $N(h)$ profiles have been redrawn with the density expressed in terms of plasma frequency (using Eq. 5).

It is seen that topside and ground-based soundings terminate at $h_{\max}F_2$, which follows from the monotonic variation of f_N and f_x with electron density. Actually, the soundings do not quite reach $h_{\max}F_2$; the topside soundings stop typically at a point M' (15 to 30 km above point M of Fig. 1) and ground-based soundings stop typically at a point M'' (10 to 20 km below M). The region $M'M''$ can be derived from simultaneous topside and ground-based soundings (Ref.3) or by extrapolation of either type of soundings. This extrapolation usually assumes that the $N(h)$ distribution can be represented by a Chapman function in the vicinity of $h_{\max}F_2$, i.e. $N(h)$ is assumed to be given by:

$$N = N_{\max} \exp \frac{1}{2} (1 - z - e^{-z}) \quad (16)$$

where

$$z = (h - h_{\max})/H$$

and

$$H = \text{scale height.}$$

The unknown parameters in Eq. (16) are determined from the known portion of the $N(h)$ profile near $h_{\max}F_2$.

There is one additional source of information which can be used to check the total profile obtained

by simultaneous topside and ground-based soundings. Topside ionograms frequently display echoes reflected from the ground (ground trace or ground echoes). These echoes, which are for frequencies greater than the maximum frequency reflected from the ionosphere, exhibit a delay which is determined by the total profile (and by the frequency of the sounder signal). It is therefore possible to check the accuracy of the total profile by comparing the observed ground echoes with the ground echoes calculated from the total $N(h)$ distribution (Ref. 3).

MATHEMATICAL TECHNIQUES USED FOR THE INVERSION OF EQ.(1)

The technique used for the inversion of Eq. (1) will be discussed for the case of vertical propagation, i.e. for the inversion of:

$$h'(f_r) = \int_{h_0}^{h_r} n' \left[N(h), f_r, B(h), \theta(h) \right] dh \quad (17)$$

Equation (17) is written:

$$h'(f_r) = \sum_{i=0}^{i=k-1} \int_{h_i}^{h_{i+1}} n' dh \quad (18)$$

where

$$\begin{aligned} h_k &= h_r \\ n' &= n' \left[N(h), f_r, B(h), \theta(h) \right] \end{aligned}$$

For each interval $\Delta h = h_{i+1} - h_i$ (or lamination), the $N(h)$ function is approximated by a simple analytic function. The number of laminations required can be minimized by choosing a function which approximates the $N(h)$ distribution over large Δh increments. A

linear approximation is, however, adequate if small height increments are chosen and this simpler representation will be used to illustrate the procedure. The linear substitution:

$$h = h_i + a_{i+1}(N - N_i)$$

$$dh = a_{i+1}dN$$

gives for a typical lamination:

$$\int_{h_i}^{h_{i+1}} n' dh = a_{i+1} \int_{N_i}^{N_{i+1}} n' dN \quad (19)$$

The integral corresponding to a given lamination is thus completely defined except for a constant a_{i+1} , which represents the value of dh/dN in the lamination. For all laminations, except the last one (h_{k-1}, h_k) , the function n' is finite* and the integral on the right hand side of Eq. (19) can be evaluated with great accuracy by numerical integration techniques, using, for example, a Gaussian quadrature formula with only three coefficients. The last lamination terminates at the reflection point where n' is infinite. The integration in this case is based upon asymptotic expressions for n' near the reflection conditions, which are of the form:

$$n' = \alpha / \sqrt{1 - \beta N}$$

where α and β are constants appropriate for the propagation

* There is one exception to this statement, and this occurs in the case of Z echoes on topside ionograms where n' becomes infinite at the start of the first lamination when $X = (1 - Y^2)/(1 - Y_L^2)$.

mode used. By letting $t^2 = 1 - \beta N$, the last integral in Eq.(19) becomes:

$$\int_{N_i}^{N_{i+1}} n' dN = -\frac{2}{\beta} \int_{t_i}^{t_{i+1}} n' t dt$$

At the reflection point, the integrand $n't$ is finite since

$$n't = n' \sqrt{1 - \beta N} = \alpha$$

Most of the techniques currently used for the inversion of Eq.(1) are based upon the above lamination concept. The laminations are implicitly specified by the choice of sampling frequencies, as illustrated by the following example based upon the ordinary $h'(f)$ function for a topside sounding. Let $f_1, f_2, \dots, f_n$ be the sampling frequencies and $h'_1, h'_2, \dots, h'_n$ be the corresponding h' values. Let N_i be the density at which reflection occurs for the frequency f_i , i.e. (from Eq. 8 and 5) $N_i = 12400 f_i^2$, where N_i is in el/cc and f_i is in MHz. It is also assumed that N_1 is the density at the satellite, i.e. $h'_1 = 0$.

Using the linear approximation of Eq. (19), the virtual range values can be written:

$$\left. \begin{aligned} h'_2 &= a_2 \int_{N_1}^{N_2} n'(f_2) dN \\ h'_3 &= a_2 \int_{N_1}^{N_2} n'(f_3) dN + a_3 \int_{N_2}^{N_3} n'(f_3) dN \\ &\dots \dots \dots \\ h'_n &= a_2 \int_{N_1}^{N_2} n'(f_n) dN + \dots + a_n \int_{N_{n-1}}^{N_n} n'(f_n) dN \end{aligned} \right\} \quad (20)$$

Each of the integrals in Eqs.(20) can be evaluated using techniques previously discussed; thus, the unknown a_i terms can be readily computed.

For the extraordinary ray the procedure is slightly more complicated, because a knowledge of both f_i and the corresponding B_i at the height h_i are required to compute N_i (see Eq.9). The procedure in this case is to initiate the calculation of each new lamination with an estimated value of B and to refine this estimate by an iteration process (Ref. 1 p. 973-975 and Ref. 4).

The laminations commonly used for $P'(f)$ to $N(h)$ inversion are of the form:

$$h = h_i + a_{i+1}(\Psi - \Psi_i) + b_{i+1}(\Psi - \Psi_i)^2 \quad (21)$$

where Ψ is either n , fN or $\ln N$. When a parabolic lamination is used ($b_{i+1} \neq 0$), the additional lamination parameters are obtained by assuming that $dh/d\Psi$ is continuous at the lamination boundaries, i.e.

$$a_{i+1} + 2b_{i+1}(\Psi_{i+1} - \Psi_i) = a_{i+2} \quad (22)$$

EXPERIMENTAL CONSTRAINTS PLACED UPON THE $P'(f)$ FUNCTION

Some difficulties arise in the inversion of Eq.(1) due to the fact that the experimental data do not yield the $P'(f)$ function for the complete altitude range of interest. These difficulties are encountered primarily with ground-based soundings due to regions QR and ST (see Fig. 1) for which the $P'(f)$ functions are not available. In some cases on topside ionograms, the

extraordinary $P'(f)$ function is not defined with sufficient accuracy at the starting point A. This usually arises when the density at the satellite is less than 200 electrons/cc. Some of the techniques developed for overcoming the above difficulties are discussed in the following sections.

UNKNOWN START ON TOPSIDE IONOGRAMS

If the density N_1 at the satellite altitude h_1 is unknown, it can be determined by the following method. The equations of the first two laminations are assumed to be linear in $\ln N$, i.e.:

$$h = h_1 + a_2 \ln(N/N_1) \quad \text{for } h_2 \leq h \leq h_1$$
$$\text{and } h = h_2 + a_3 \ln(N/N_2) \quad \text{for } h_3 \leq h \leq h_2$$

It is then assumed that the correct value of N_1 will yield $a_2 = a_3$. Various values of N_1 are tried (by an iteration process) until a_2 and a_3 agree within one-tenth of one percent. This slope matching technique has been tested extensively with ionograms where N_1 could be accurately measured by conventional scaling techniques. It was found that, for ionograms where N_1 is well defined, conventional and slope matching techniques have comparable accuracy. Results obtained with the slope matching technique have cast considerable doubt upon the determination of N_1 using the method introduced by Hagg (Ref. 5) which is based upon topside sounder plasma resonance observations under conditions

of low N_1 . This method yields values of N_1 which are typically one-third of the slope matching technique values. Furthermore, the Hagg beat values (so-called because they are determined from the observed beat frequency between the FH and FT resonances) yield rather questionable $N(h)$ profiles (see Fig. 4). Lockwood (companion paper) and Colin (private communication) have also used the slope matching technique (or similar procedures) to compute N_1 and they have reached similar conclusions concerning the Hagg beat. The low N_1 Hagg beat values have been attributed to plasma wave dispersion effects associated with the FH and FT resonances (Ref. 6).

UNKNOWN STARTS ON GROUND-BASED SOUNDINGS

The $P'(f)$ function for a ground-based sounding can be written:

$$\int_0^{h_k} n' dh = h_Q + \int_{h_Q}^{h_R} n' dh + \int_{h_R}^{h_k} n' dh$$

where the letters Q and R refer to Fig. 1, and where h_k refers to a reflection point above point R. The altitude h_Q is the altitude below which n' can be considered equal to unity for the frequencies of interest. The group index n' cannot be considered equal to unity in the region QR even though this region yields no echoes on conventional ionograms. The procedures used

are different on daytime and on nighttime ionograms and these two cases will be discussed separately.

(a) daytime ionograms

One solution (See Ref. 7 p. 120-122), which is similar to the slope matching technique, is to assume that the region QR is a simple analytic extension of the profile above point R. Another approach, based upon rocket results (Fig. 5), is to assume that the density is 1000 el/cc at 80 km, and that it increases exponentially up to point R. This gives fairly good results with midlatitude, midday ionograms.

(b) nighttime ionograms

Analytic extensions of the profile above point R could also be assumed for the region QR, but more reliable results can usually be obtained by making use of the ordinary and extraordinary traces which are of comparable quality on nighttime ionograms. The procedure is to assume an arbitrary density value at Q and to compute from the ordinary trace the corresponding $N(h)$ profile. The extraordinary $P'(f)$ function corresponding to this profile is then computed and compared to the observed extraordinary $P'(f)$ function at m values of sounding frequencies. The standard deviation σ between the computed and the observed extraordinary $P'(f)$ values is:

$$\sigma = \sqrt{\sum (d_i^2 / m)} \quad (23)$$

where d_i represents the vertical height differences at $f = f_i$. The process is repeated for other assumed densities at Q and the density at Q which yields the minimum value of σ is taken as the starting density. The quantity σ for typical nighttime midlatitude ionograms is shown in Fig. 6 as a function of the assumed plasma frequency at Q . A value of $h_Q = 150$ km was used for this calculation. Also indicated on Fig. 6 is the altitude at which the electron density reaches a value of 10^5 el/cc. Extensive tests of this technique have given a high degree of consistency in the 150 km starting value obtained at one sounder location (Wallops Island), namely

$$0.2 \text{ MHz} \leq (fN) \leq 0.4 \text{ MHz.}$$

Thus an empirical starting value of $fN = 0.3$ MHz could be used in cases when the two traces cannot be scaled with sufficient accuracy to permit the above determination of N_Q .

THE VALLEY PROBLEM

The valley ambiguity (unknown region ST) can in principle be substantially minimized by using a technique similar to the one described for the unknown start on nighttime ground-based soundings. In this case a model of the E valley is arbitrarily selected and the quantity σ (Eq. (23)) is computed for various valley depths. The desired valley is

the one which yields the minimum value of σ . The effect of the assumed valley upon the resulting $N(h)$ profile is shown in Fig. 7, which is for a Wallops Island ionogram obtained on 7 March 1970 at 1519 EST. The shape of the valley (a triangular wedge on this semi-logarithmic plot) is one of many assumed by other authors (Refs. 8 and 9). It is physically unrealistic but convenient for computer programming. Furthermore the shape of the valley is too variable to justify the use of a more aesthetic representation. The purpose of the valley is to improve the accuracy of the profile above the valley (rather than to provide meaningful data within the valley). The profiles shown in Fig. 7 would normally be derived from the ordinary trace. These profiles and two additional ones for a 90% and a 70% valley respectively have been used to compute the corresponding family of extraordinary traces above E_{max} shown in Fig. 8. The solid points which represent the observed X-trace are seen to agree best with a valley of 80%.

The valley determination illustrated by Figs. 7 and 8 was possible because the X trace was well defined for frequencies immediately above the extraordinary ray E-region critical frequency $f_x E$. This requirement is often not met and it is seen, by inspection of Fig. 8,

that the comparison would have been much less meaningful if the ionogram had not shown an X trace for frequencies less than say 4.5 MHz (particularly in view of the ± 5 km scaling uncertainty).

The valley calculations (when feasible) yield fairly consistent results, and these results can be used to estimate the valley depth in cases when the extraordinary trace cannot be used for this purpose. For midlatitude midday conditions both valley calculations, as illustrated above, and rocket data (Refs. 10 and 11) show that the minimum E-valley density is typically 80 to 90% of the density at E_{max} (point S of Fig. 1).

PROBLEMS ARISING FROM NON-VERTICAL PROPAGATION

The routine procedure for the inversion of Eq. (1) is to assume that the $P'(f)$ function represents virtual heights measured at vertical incidence. This assumption would, for $B = 0$, be equivalent to stating that the sounder is receiving echoes from a spherically stratified region of the ionosphere. This region for a ground-based sounder would be a vertical cylinder having a diameter of typically 10 km. For a topside sounder, which can move horizontally up to 200 km while a complete ionogram is obtained, the spherical stratification would have to hold over a vertical region whose projection

on the earth's surface would be roughly a 10 by 200 km rectangle. There is usually a change in altitude (and also some minor changes in B and θ) associated with the horizontal motion of the top-side sounder. These effects can be taken into consideration (see companion paper by Lockwood) by assuming that the $N(h)$ profile is a function of altitude only and that the successive soundings begin at a new reference altitude (and corresponding density).

The spherical stratification concept usually applies to the constant electron density contours and, for $B = 0$, this assumption would yield constant phase index contours. The presence of the terrestrial magnetic field introduces modifications in the constant phase index contours, and causes the ray paths to be deviated from the vertical mostly near the reflection points. Theoretical investigations of this problem (Colin, private communication) indicate that no serious errors are introduced in the virtual height calculations by assuming that the phase index contours are the same as the electron density contours. A more important effect of the magnetic field is the occasional presence of field-aligned irregularities which can act as wave guides and cause echoes (in the extraordinary mode) to be field-aligned. This can be recognized by an

experienced observer, and in this case the analysis (done for $\Phi = 0$) yields a field-aligned $N(h)$ profile. From a sequence of these field-aligned profiles, a sequence of vertical profiles can be derived. The results of an analysis of this type are shown in Fig. 9.

Departures from spherical stratification can sometimes be inferred from a time sequence of ionograms. In the case of ground-based soundings it can be detected (when severe tilts are present) from the fact that multiple echoes (two-or-more round trips) do not give virtual heights in harmonic relationship to the first (one-round trip) echo virtual height. For example, if h' is the first echo virtual height, the second echo virtual height should be $2h'$ for spherical stratification. If the constant density contours make an angle γ with the horizontal, the second echo virtual height is $2h' \cos \gamma$. Departures from spherical stratification could also be inferred from a closely spaced network of ground-based sounders. Analysis techniques which can take into consideration these departures from spherical stratification are currently under investigation (see companion paper by McCulley). Routine inversion techniques, however, assume that the $N(h)$ distribution corresponding to a given ionogram is a function of altitude only, and

that this $N(h)$ distribution does not change significantly during the 10-to-30 seconds required to obtain an ionogram.

ACCURACY OF THE INVERSION TECHNIQUES

The accuracy of the mathematical techniques used in the inversion of Eq. (1) has been tested extensively (see Ref. 1 p. 967 to 970). These tests have shown that the integration techniques do not introduce significant errors in the inversion of Eq. (1). For example, on topside ionograms the error in altitude for a given density is typically less than one kilometer.

Some errors are introduced in the inversion of Eq. (1) for ground-based soundings due to the discontinuities in the $P'(f)$ function at the starting point and at the E valley. These discontinuities introduce errors in altitude (up to 10 km) at the corresponding places on the $N(h)$ profile, more specifically at the starting point and just above the E valley. The errors for the $N(h)$ profile above the E valley decrease monotonically with altitude and near $h_{max}F2$ the calculated $N(h)$ profiles are affected at most by 1 or 2 km by the uncertainties at the lower altitudes.

It would therefore be expected that ionograms obtained simultaneously by a ground-based ionosonde

and by a topside sounder directly overhead would yield $N(h)$ profiles which should agree near $h_{\max}F2$. Comparisons of this type have yielded disagreements (Ref. 3) which are several times greater than the errors attributable to scaling accuracy and to the mathematical techniques used for the inversion of Eq. (1). The results suggest that the error is roughly proportional to the length of the propagation path. Since the maximum propagation path (within the ionosphere) is usually several times greater for a topside sounding than for a ground-based sounding, one would attribute this discrepancy primarily to the calculated topside $N(h)$ profile. On this basis the topside profile appears to be too low by about 3 to 5 percent of the distance d between the topside sounder and the reflection point. One test for the accuracy of the resulting total (or composite) profile is to calculate the corresponding total content $\int_0^{h_s} Ndh$ (where h_s is the satellite altitude) and to compare the results with an independent measurement of the total content. Comparisons of this type using data from GEOS-2 to compute $\int Ndh$ have shown consistently that the total content for the calculated composite profile was too low. By raising the topside profile by 3 to 4 percent of the distance d , the two measurements of $\int Ndh$ can be brought into agreement. In some cases, an additional

check was possible using the topside ground trace. This procedure is illustrated by Fig. 10 and 11. The composite profile (solid line) shown in Fig. 10 was obtained from simultaneous topside and ground-based observations. The corresponding ordinary and extraordinary ground traces are shown in Fig. 11 (solid line). The points (with indicated error bars) scaled from the observed ground traces are seen to be significantly lower than the computed ground traces. By raising the topside profile as shown by the dashed line in Fig. 10, the corresponding computed ground traces (dashed lines in Fig. 11) are brought in much closer agreement with the observed values.

The small but puzzling discrepancy between topside and ground-based sounding suggests that some cumulative errors arise in the observations due perhaps to irregularities in the ionosphere causing the propagation paths to deviate from the vertical direction. The discrepancy does not seem to be due to large-scale departures from spherical stratification, as could be inferred from the analysis of ionogram sequences.

Another possibility not discussed in the report is that cumulative errors arise in the analysis due to one of the many assumptions made in the magneto-ionic theory (cold plasma treatment of the ionosphere, WKB approxi-

mation, idealized reflection conditions, group velocity representation of the signal velocity, etc). Although these approximations have been accepted for several decades, a complete evaluation of their effects has not been made in the topside ionosphere.

SUMMARY

1) The $P'(f)$ to $N(h)$ inversion in ionospheric soundings is based upon the following assumptions:

- a) spherically stratified medium (except in special techniques under development which make allowance for gradients),
- b) medium which does not change during the sounding,
- c) vertical propagation (except in more elaborate techniques used, for example, to deal with geomagnetic field-aligned propagation), and
- d) simple ray theory of wave propagation in the ionosphere.

2) The most accurate inversion technique is based upon:

- a) lamination concept and step-by-step solution,
- b) lamination model optimized for representative $N(h)$ distributions,
- c) numerical integration with change of variable to keep the integrand finite, and
- d) iteration (with topside extraordinary $P'(f)$ function) to find the upper limit of integration.

- 3) Special problems arise, particularly with the $P'(f)$ function obtained by ground-based soundings, when the $P'(f)$ function is not defined over the complete altitude range of interest. This leads to:
- a) starting point problem, and
 - b) valley problem (for daytime ground-based soundings).
- 4) The solutions to these special problems are based upon:
- a) redundancy of the data (ordinary and extraordinary $P'(f)$ functions);
 - b) estimated parameter values derived from statistical data accumulated from previous $P'(f)$ to $N(h)$ inversions, or from other techniques, such as in situ rocket measurements;
 - c) (in some cases) extrapolations or "slope matching techniques".
- 5) The accuracy of the $N(h)$ profiles derived by inversion of the $P'(f)$ function is typically better than 5 percent of the length of the propagation path in the ionosphere. The errors in the $N(h)$ profiles are apparently due to assumptions made in the analysis, since they are several times greater than the error attributable to the mathematical techniques used in the inversion process. Although the human element was not stressed in this paper, it is an important factor in the ultimate accuracy achieved with a given inversion technique.

The human element enters in the initial recognition and accurate scaling of the $P'(f)$ function, in the evaluation of the validity of the assumptions made for a given experimental condition, and in the final acceptance (or rejection) of the results given by the inversion process.

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FIGURE CAPTIONS

- Fig. 1 Vertical electron density distributions based upon simultaneous topside and ground-based observations at Wallops Island, Virginia (latitude 37.84° N, longitude 75.47° W, $fH = 1.45$ MHz, $\theta = 69^{\circ}$). The daytime curve is for June 18, 1968 at 1200 EST and the nighttime curve is for June 4, 1968 at 0245 EST. The two $N(h)$ profiles corresponded to the same magnetic index ($Kp = 3$) and 10.7 cm solar flux ($Sf = 144$). The altitude difference between S and T was made about 15 km greater than observed in order to show the E valley more clearly.
- Fig. 2 Vertical distribution of plasma frequency (dashed-curve) corresponding to the daytime $N(h)$ profile of Fig. 1, and corresponding ordinary ray $P'(f)$ functions (solid curves) for topside and ground-based soundings. The virtual range scale is one half the altitude scale to keep the ionograms from overlapping.
- Fig. 3 Vertical distribution of plasma frequency (dashed-curve) corresponding to the nighttime $N(h)$ profile of Fig. 1, and corresponding ordinary ray $P'(f)$ functions (solid curves) for topside and ground-based soundings. The virtual range scale is one half the altitude scale to keep the ionograms from overlapping.

- Fig. 4 Comparisons between two $N(h)$ profiles derived from the same ionogram using the Hagg-beat start (dashed-curve) and the slope matching start (solid curve).
- Fig. 5 Rocket results (Ref. 12) showing D and E regions. The lower part of the profile (for which the $P'(f)$ function is not normally available) can be approximated by the indicated straight segments.
- Fig. 6 The function σ versus plasma frequency at 150 km for typical midlatitude nighttime ionograms. The effect of the starting point upon the resulting $N(h)$ profile is indicated by the dashed line which shows the altitude at which the density is 10^5 el/cc.
- Fig. 7 Effect of assumed valley upon calculated $N(h)$ profiles.
- Fig. 8 Calculated X traces for $N(h)$ profiles of Fig. 7 and for profiles corresponding to two additional valleys (not shown in Fig. 7). The observed X trace values are shown by the solid points.
- Fig. 9 Electron density contours derived from topside field-aligned traces.
- Fig. 10 Composite profile obtained by simultaneous topside and ground-based soundings at Wallops Island, Virginia. Solid curve is for calculated profile. Dashed curve is for revised profile based upon the ground trace calculations (see Fig. 11).
- Fig. 11 Ground traces for calculated and revised profiles of Fig. 10. The observed ground trace data are the points with the indicated error bars.

Fig. 1

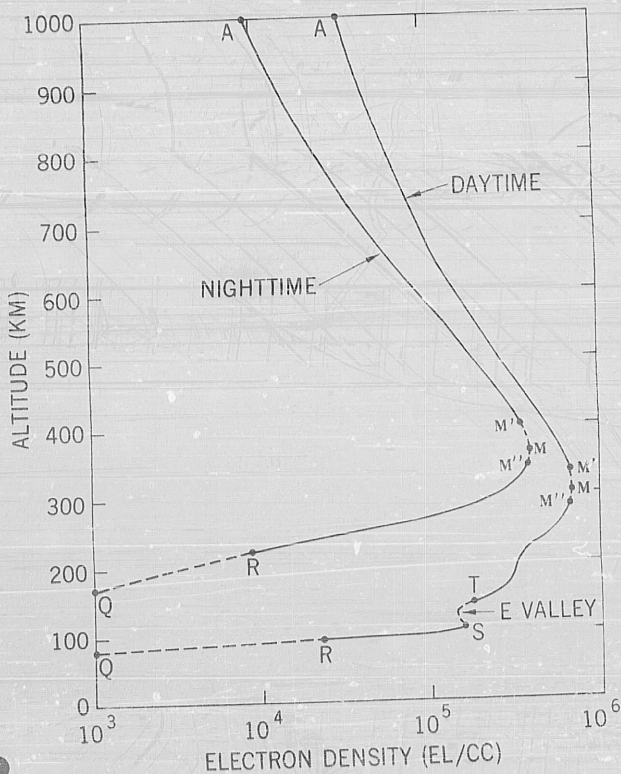


Fig. 2

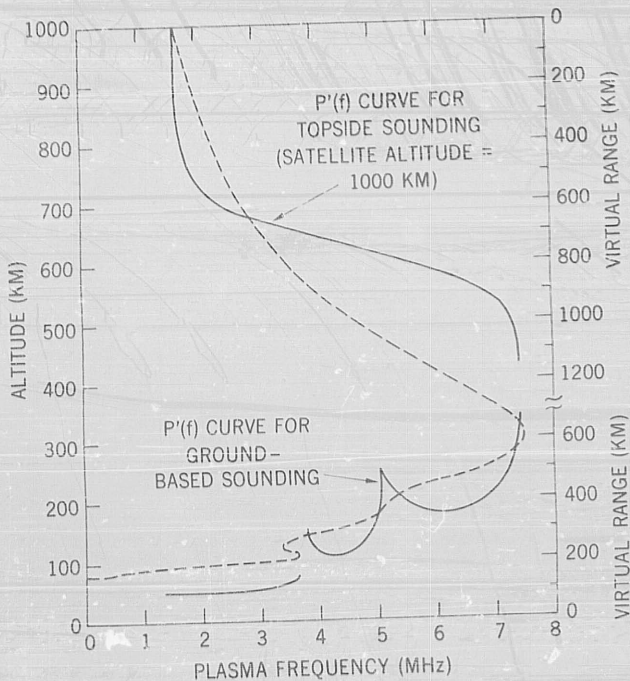
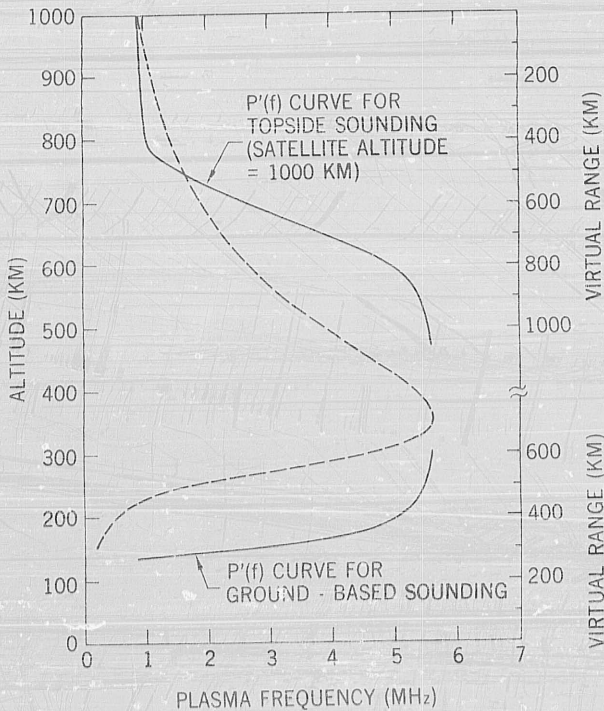
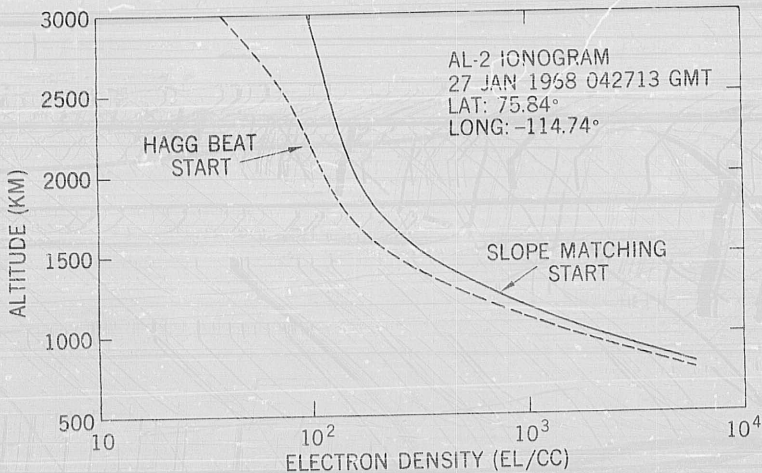


Fig. 3





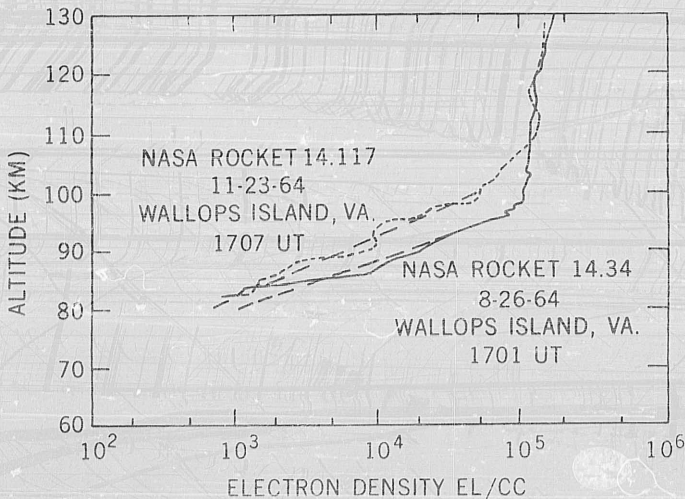
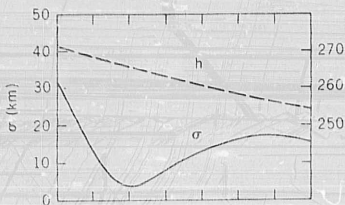
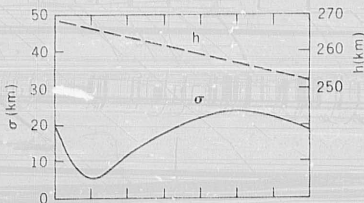


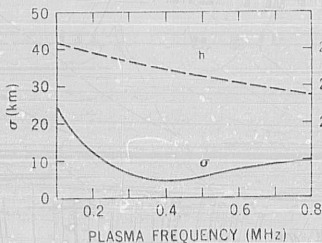
Fig. 6



WALLOPS ISLAND
4 APRIL 1968
2145 EST
 $h_{\text{maxF2}} = 380 \text{ km}$
 $N_{\text{maxF2}} = 4.8 \times 10^5$



WALLOPS ISLAND
23 MAY 1968
2215 EST
 $h_{\text{maxF2}} = 380 \text{ km}$
 $N_{\text{maxF2}} = 7.6 \times 10^5$



WALLOPS ISLAND
28 MAY 1968
2145 EST
 $h_{\text{maxF2}} = 370 \text{ km}$
 $N_{\text{maxF2}} = 6.8 \times 10^5$

Fig. 7

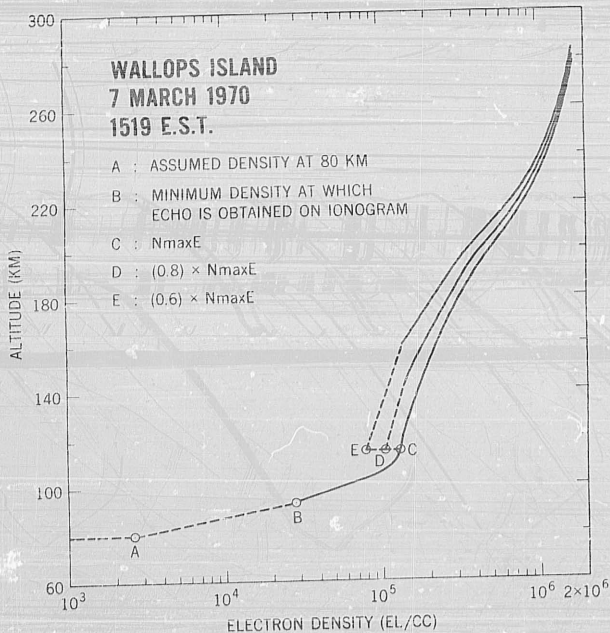
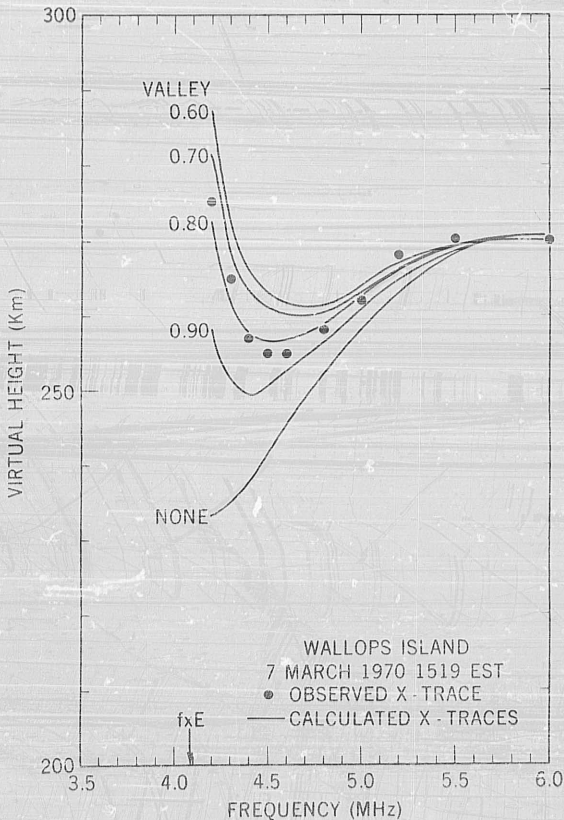


Fig. 8



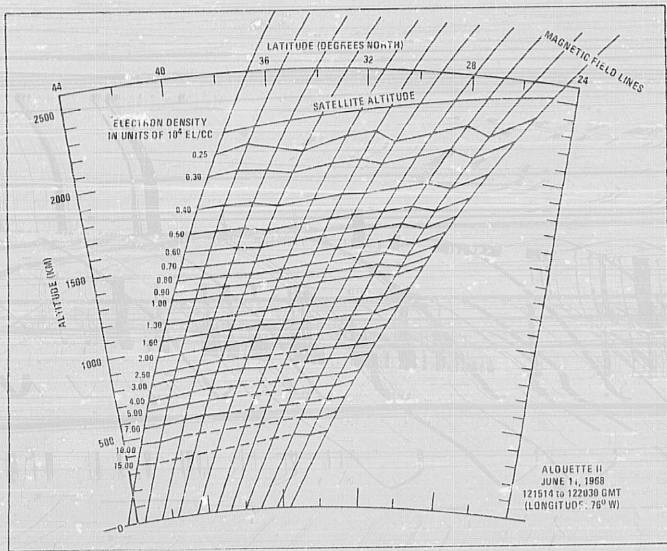


Fig. 9

Fig. 10

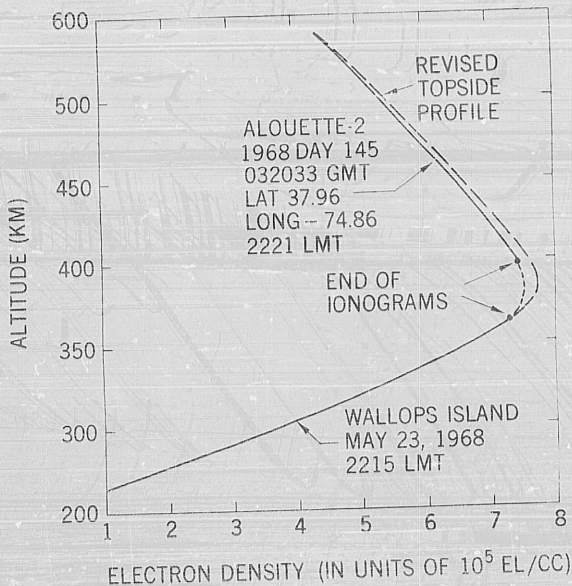
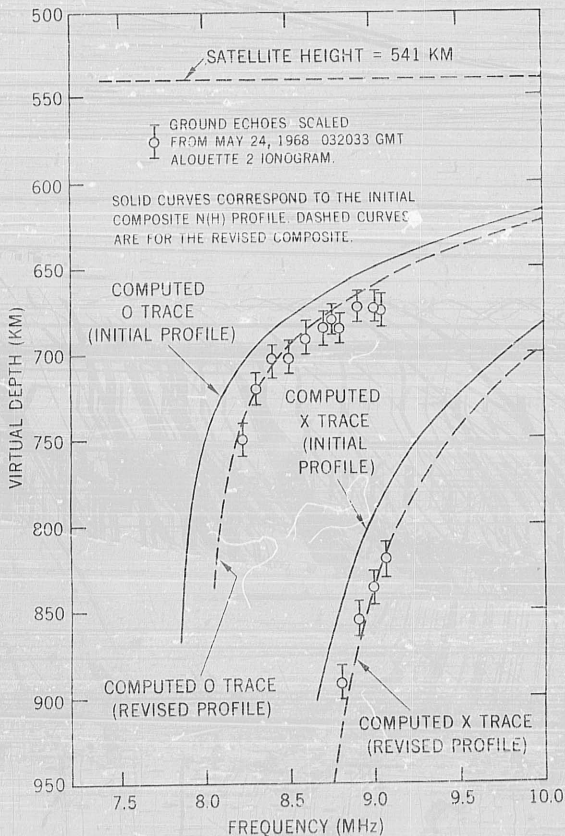


Fig. 11



```

//LBJ002 JBB (L300*23856,T,MAC001,HC0H00),029,MSGLEVEL=1 02-A0011
// EXEC FORTRANH
XKDEFAL'T PRIC NBLK=20 00010000
XXSOURCE EXEC RGMRIEAA00,REGION=320K 00020000
XXSYSLIN DD DSN=FE0BJM00,DISP=(MOD,PASS),UNIT=LINK, X00030000
XX SPACE=(3200,(6NBLK,10),,ROUND), X00040000
IEF631 SUBSTITUTION JCL = SPACE=(3200,(20,10),,ROUND),
XX DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200) 00050000
XXSYSPRINT DD SYSOUT=A,DCB=(RECFM=VB,LRECL=137,BLKSIZE=7200) 00060000
XXSYSPUNCH DD DUMMY,DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200) X00070000
XX* TO GET A DECK, ADD THE FOLLOWING CARD TO YOUR DECK X00080000
XX* //SOURCE,SYSPUNCH DD DSN=DECK,SYSOUL=B 00090000
XXSYSOUL DD UNIT=LINK,SPACE=(7200,(6NBLK,4)) 00100000
IEF631 SUBSTITUTION JCL = UNIT=LINK,SPACE=(7200,(20,4))
XXSYSOUL DD UNIT=LINK,SPACE=(7200,(1,1)) 00110000
//SOURCE,SYSLIN DD *
IEF2351 ALLOC. FOR LE180002 SOURCE
IEF2371 333 ALLOCATED TO SYSLIN
IEF2371 332 ALLOCATED TO SYSPRINT
IEF2371 100 ALLOCATED TO SYSOUT1
IEF2371 100 ALLOCATED TO SYSOUT2
IEF2371 233 ALLOCATED TO SYSLIN

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TOPSIDE


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1SN 0036 READ(5,103) HT,DIP,FHS,DLAT,DLONG
1SN 0037 READ (5,103) (HO(I),F(I),I=1,N)
1SN 0038 103 FORMAT (F10.4)
1SN 0039 WRITE (6,3011) TITLE
1SN 0040 3011 FORMAT (1H1,5X,20A4/1H ,5X,20A4)
1SN 0041 I=(METHOD-1)*500,500,C)
1SN 0042 500 WRITE(2,502)
1SN 0043 502 FORMAT(1H0,25HFIELD G, LINEAR IN LOG(N))
1SN 0044 GO TO 503
1SN 0045 503 WRITE(2,504)
1SN 0046 504 FORMAT(1H2,27HFIELD G, PARABOLIC IN LOG(N))
1SN 0047 WRITE(2,503)
1SN 0048 503 FORMAT(1H0,10HINPUT DATA)
1SN 0049 503 WRITE (2,104) IY, IDY, IIZ
1SN 0050 104 FORMAT(1H5,8HFIELD 1012,6X,3HDAY14,5X,4H1IME17)
1SN 0051 WRITE (2,2116)
1SN 0052 2116 FORMAT(1H0,27HLOCATION FROM WORLD MAP, ESTIMATED DIP AND FHS.)
1SN 0053 WRITE (2,105) HT,DIP,FHS,DLAT,DLONG
1SN 0054 105 FORMAT (1H ,3HHT=F10.4,5X,4HDIP=F10.4,5X,6HFHS=F10.4,5X,5HDLAT=F10.4,5X,6HDLONG=F10.4)
1SN 0055 2009 WRITE (2,2009)
1SN 0056 2009 FORMAT (1H5,7HX TRACE)
1SN 0057 WRITE (2,106)
1SN 0058 106 FORMAT(1H ,3(3X,1HE,6X,2HNP,2X))
1SN 0059 WRITE(2,107)(F(I),HO(I),I=1,N)
1SN 0060 107 FORMAT(11X,F6.3,1X,F6.1)
C
C USE FIELDG TO COMPUTE FH AT SATELLITE AND DIP, IN PLACE OF VALUES
C READ IN ON DATA CARDS. IF FIELDG NOT AVAILABLE, OMIT THIS CALL.
C CALL FIELDG(DLAT,DLONG,HT,DATE,20,LO,PN,B6,PV,RT)
RT = RI
RV = BV
HH =DSORT(RT*3 - RV**2)
BVH = BV/HH
DIP =DATAN(BVH)/57.29573
FH(1)=RT*2.8000E-05
FHS = FH(1)
WRITE (2,3115)
1SN 0070 3115 FORMAT(1H5,73HLOCATION FROM WORLD MAP, DIP AND FHS AT SATELLITE CD
IMPUTED FROM FIELD G.)
1SN 0071 WRITE (3,105) HT,DIP,FHS,DLAT,DLONG
C
1SN 0072 DIP =DSORT(DIP*DIP)
1SN 0073 WRITE (2,108)
1SN 0074 108 FORMAT (1H0,2X,1HE,16X,4HELOC,14X,6HHEIGHT,4X,3HITERATION,3X,2HEH,
VALX,12HPREVIOUS HGT,9X,5HSLCP)
A=(90.-DIP)/57.29577
COH=FCOS(A)
1SN 0075
1SN 0076
1SN 0077 2007 FH(1) = FHS
1SN 0078 TH(1) = HT
1SN 0079 TEST=FH(1)+0.001
1SN 0080 FREQ = F(1)
C EXT, RAY EXIT FREQ, MUST BE GREATER THAN FHS
1SN 0081 IF (FREQ - 15.0 ) 4000,9.9
1SN 0082 4000 IF (FREQ - TEST ) 9.10,10
1SN 0083 9 F(1) = TEST

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1SN 0084      I = 1
1SN 0085      METHOD = 1
1SN 0086      WRITE(6,13)1
1SN 0087      13 FORMAT(1H ,46FREQUENCY READ TOO LOW ON INPUT DATA POINT NO.12,2X,
1SN 0088      15SHYPROGRAM IS LINEAR IN LOG(N) FOR REMAINDER OF LOGOGRAM)
1SN 0089      10 DEN(1)=(F(1)*(F(1)-FH(1)))*12400.0
1SN 0090      ELCC = DEN(1)
1SN 0091      FA = F(1)
1SN 0092      NL = N
1SN 0093      WRITE(6,17,3)FA,ELCC,HT
1SN 0094      173 FORMAT(1H0,F12.4,5X,F12.4,5X,F12.4)
1SN 0095      FH(1) = FHS
1SN 0096      DO 28 I=2,N
1SN 0097      15 DD = 0.0
1SN 0098      IO = 0
1SN 0099      IF(I-NL)4,0,28
1SN 0100      0 TEST = F(I-1) + 0.001
1SN 0101      IFREQ = F(I)
1SN 0102      IF(FREQ-TEST)29,12,12
1SN 0103      29 NL = NL-1
1SN 0104      FA = F(I)
1SN 0105      METHOD = 1
1SN 0106      C BAD DATA POINTS ARE REJECTED IN DD 33
1SN 0107      DD 33 I=1,NL
1SN 0108      HP(I) = HP(L+1)
1SN 0109      33 F(L1) = F(L+1)
1SN 0110      WRITE(6,11)6A
1SN 0111      11 FORMAT(1H , 11)DATA FOR F=F0,2X,17)HAS BEEN REJECTED)
1SN 0112      GO TO 15
1SN 0113      C INITIAL FH(I) BASED UPON 0.1 PER CENT INCREASE IN DENSITY
1SN 0114      12 FH(I) = F(I) - (F(I-1)-(F(I-1)-FH(I-1)))/(0.999*F(I))
1SN 0115      AAA = 1.15*FH(I-1) - FH(I)
1SN 0116      IF(AAA)900,901,901
1SN 0117      900 FH(I) = 1.15*FH(I-1)
1SN 0118      901 GYRO = FH(I)
1SN 0119      TH(I) = TH(I-1)
1SN 0120      HGT = H(I-1)
1SN 0121      FAE = F(I)
1SN 0122      FAEA = FA*FA
1SN 0123      M = 2
1SN 0124      C YR=Y AT REFLECTION POINT
1SN 0125      14 YR = FH(I)/FA
1SN 0126      HGTA = TH(I)
1SN 0127      GYRO = FH(I)
1SN 0128      DD 24 J=N,I
1SN 0129      F1F1=F(J-1)*(F(J-1)-FH(J-1))
1SN 0130      F2F2=F(J)*(F(J)-FH(J))
1SN 0131      Y1 = FH(J-1)/FA
1SN 0132      Y2 = FH(J)/FA
1SN 0133      X1 = F1F1/FAEA
1SN 0134      X2 = F2F2/FAEA
1SN 0135      C CHANGE FROM VARIABLE X TO VARIABLE Y
1SN 0136      T1=DSORT(1,0-(X1/(1,0-YR)))
1SN 0137      T1 = 0.5
1SN 0138      S2=C*0
1SN 0139      C B3 AND C4 ARE USED IN FORMULA TO CHANGE Y WITHIN LAMINATION

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15N 0134      BS = DLG(Y2/Y1)/3.0
15N 0135      V=LOG(X2/X1)
15N 0136      TF=(J+1)*.18,18
15N 0137      T2 = 0.0
15N 0138      IF(METHOD=1)151,151,506
15N 0139      506 IF(1=2)151,151,155
15N 0140      155 IF(10=1)151,155,152
15N 0141      151 ALIM = 1.0
15N 0142      PA = 1.0
15N 0143      RB = 1.0
15N 0144      GO TO 156
15N 0145      152 AA(1) = AA1
15N 0146      153 BB(1) = (TH(1)-TH(1-1)-AA(1)*V)/(V*V)
15N 0147      AA(I+1)=AA(1)+(.01)*BB(1)*V
15N 0148      ALIM = AA(I+1)/AA(1)
15N 0149      GO TO 154
15N 0150      10 T2=DSORT(1.0-(X2/(1.0-YR)))
15N 0151      IF(METHOD=1)151,151,506
15N 0152      506 ALIM = 1.0
15N 0153      154 RB = BB(J)/AA(J)
15N 0154      RA = 1.0+RB*V
15N 0155      156 C2 = (DEXP(B2)-1.0)/(V*RA)
15N 0156      C GAUSSIAN INTEGRATION
15N 0157      20 DO 603 K=1,3
15N 0158      Y = 0.5*(T1-T2)*SS(K)+T1+T2
15N 0159      X2(1.0-T1+T2)=(1.0-YR)
15N 0160      A = DLG(X2/X1)
15N 0161      Y2 = Y2/(1.0+C2*RA*(1.0+RB*(2.0-V-A)))*.3
15N 0162      IF (Y=0.0002) 601,601,603
15N 0163      601 Y = YR
15N 0164      C UX IS VALUE OF INTEGRAND AT THE REFLECTION POINT
15N 0165      UX=(.007107*(1.0-A-Y)/(1.0-Y))*(1.0/DSORT(1.0+CPH*CPH)))
15N 0166      U = ((1.0-Y)*DSORT(1.0+(3.0+C2*RA*ALIM)/(1.0-Y)))
15N 0167      603 YL = Y + CPH
15N 0168      YT2 = Y*Y*(1.0+CPH*CPH)
15N 0169      IF(CPH=0.000) 603,604,604
15N 0170      604 A = YT2/(2.0+YL)
15N 0171      B = B/(1.0-X)
15N 0172      PSI=UATAN(B)
15N 0173      A=(1.0+DSIN(PSI))*DSORT(1.0+RA*RB)
15N 0174      SX = 1.0-A*YL
15N 0175      GO TO 609
15N 0176      606 PSI = 1.570795
15N 0177      SX = 1.0 - (Y*Y)/(1.0-X)
15N 0178      605 R = Y/SX
15N 0179      IF(0.99990-R)157,20,612
15N 0180      C REJECTS BAD DATA CARDS
15N 0181      612 U=DSORT(1.0-R)
15N 0182      C = (1.0-SX)/(2.0*SX)
15N 0183      PSI1=(1.0+X)*DSIN(PSI)/(1.0-X)
15N 0184      UP = (1.0 + B*CPH)/U
15N 0185      UX = (UP * Y)/X
15N 0186      603 S1 = S1+UX*(K)
15N 0187      UX2=UX*DLG(X/X1)
15N 0188      SR=S1+UX2*(K)

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15N 0186 605 CONTINUE
15N 0187 SA=S1*(T1-T2)*C.5
15N 0188 ASUM=2.*A*(1.-YB)*SA
15N 0189 SB=S2*(T1-T2)*C.5
15N 0190 BSUM=2.*B*(1.-YB)*SB
15N 0191 IF(J-I) 23,25,25
15N 0192 23 DP=DP-AA(J)*ASUM-BR(J)*BSUM
15N 0193 24 CONTINUE
15N 0194 25 IF(I-2) 60,60,61
15N 0195 60 AA(2)=-HP(2)/ASUM
15N 0196 TH(2)=TH(1)+AA(2)*DLOG(X2/X1)
15N 0197 AA1 = AA(2)
15N 0198 GO TO 62
15N 0199 61 IF(METHOD-1)70,70,810
15N 0200 510 IF(I0-2)71,71,71
15N 0201 70 AB=(DP-HP(1))/ASUM
15N 0202 TH(1)=TH(I-1)+AB*DLOG(X2/X1)
15N 0203 AA(1)=AB
15N 0204 BB(1)=0.0
15N 0205 HGT=TH(1)
15N 0206 IF(METHOD-1)62,62,67
15N 0207 71 BB11 = (DP-AA(1)*ASUM-HP(1))/BSUM
15N 0208 V=DLOG(X2/X1)
15N 0209 TH(1)=TH(I-1)+AA(1)*V+BB11 *V*V
15N 0210 BB(1) = BB11
15N 0211 62 HGT=TH(1)
15N 0212 C CONVERGENCE TEST TO INSURE THAT SUCCESSIVE HT. ARE WITHIN 0.01 KM
15N 0213 A = HGT-HGTA
15N 0214 A = 0.0001- A*A
15N 0215 IF(A) 27,30,30
15N 0216 27 IQ = IQ+1
15N 0217 V=1
15N 0218 C ITERATE ONLY FOR LAST LAMINATION (M=1), 10 ITERATIONS MAX. NO.
15N 0219 IF(I0-9)66,66,30
15N 0220 C
15N 0221 C USE FIELD TO COMPUTE FH AT ITH POINT. IF NOT AVAILABLE, REPLACE
15N 0222 C THIS CALL WITH THE FOLLOWING INVERSE-CUBE APPROXIMATION:
15N 0223 C FH(I)=FPC*(((6371.0+HT)/(6371.0*HGT(I)))**3)
15N 0224 C WHERE HT=SATELLITE HEIGHT.
15N 0225 66 CALL FIELD GCOLAT,DLOG,HGT,DATE,20,IQ,BN,BE,BV,BT)
15N 0226 FH(I)=BT*2.000E-08
15N 0227 GYRO = FH(I)
15N 0228 DEN(I) = (F(I)+F(I)-FH(I))*12400.0
15N 0229 ELCC = DEN(I)
15N 0230 A = DEN(I) - DEN(I-1)*1.001
15N 0231 C IF DENSITY DOES NOT INCREASE BY AT LEAST 0.1 PER CENT, REJECT PT
15N 0232 IF(A)29,14,14
15N 0233 30 V = DLOG(X2/X1)
15N 0234 AA1 = AA1*(2.0)*BR(I)*V
15N 0235 WRITE(6,172)FA,ELCC,HGT,IQ,GYRO,HGTA,AA1
15N 0236 172 FORMAT(1H, F12.6,X,F12.6,X,F12.4,X,F12.4,X,F12.6,X,F12.6,X,F12.4,X,
15N 0237 1F12.4)
15N 0238 28 CONTINUE
15N 0239 C INTERPOLATION ROUTINE
15N 0240 N = NL
15N 0241 DO 230 I=1,N

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1SN 0232      280  DENL(1) = CLOG(DEN(1))
1SN 0233      DEN=1
1SN 0234      M=1
1SN 0235      K=1
1SN 0236      DO 816 L=1,N
1SN 0237      KTK=1
1SN 0238      D2A = DEN(L)
1SN 0239      D2B = DEN(L+1)
1SN 0240      Z2A = TH(L)
1SN 0241      Z2B = TH(L+1)
1SN 0242      H = (Z2B-Z2A)/(DEN(L+1)-DEN(L))
1SN 0243      810  K=K+1
1SN 0244      D1 = DENREF(K)
1SN 0245      IF(D1-D2A)*D10,D12,D13
1SN 0246      812  DENINT(M) = 01
1SN 0247      ZINT(M) = Z2A
1SN 0248      M=M+1
1SN 0249      GO TO 810
1SN 0250      813  IF(D1-D2B)*D14,D15,D16
1SN 0251      814  DENINT(M) = D1
1SN 0252      IF(METHOD-1)*D17,D17,D19
1SN 0253      817  ZINT(M) = Z2A+(ALOG(D1)-DEN(L))*H
1SN 0254      M=M+1
1SN 0255      GO TO 810
1SN 0256      819  V= DLOG(D1/D2A)
1SN 0257      ZINT(M)=Z2A+A*(L+1)*V+B*(L+1)*V*V
1SN 0258      M=M+1
1SN 0259      GO TO 810
1SN 0260      815  DENINT(M)=D1
1SN 0261      ZINT(M)=Z2B
1SN 0262      M=M+1
1SN 0263      816  CONTINUE
1SN 0264      M=M+1
1SN 0265      WRITE(6,701)
1SN 0266      WRITE(6,700)(ZINT(M),DENINT(M),M=1,M)
1SN 0267      N = N+1
1SN 0268      XMAX = 3000.
1SN 0269      GGG = 50.0
1SN 0270      CALL FIXIT (TH,DENL,N,GGG,XMAX,X3,Y3,NX3,IFLAG,METHOD,AA,BB)
1SN 0271      DO 281 I=1,NX3
1SN 0272      281  DEN(I) =DEX*(Y3(I))
1SN 0273      WRITE(6,702)
1SN 0274      WRITE (6,703)(X3(I),DEN(I), I=1,NX3)
1SN 0275      700  FORMAT(5(2X,F6.1,E13.6))
1SN 0276      XC=3000.
1SN 0277      282  IF(X3(1)-XC)283,283,284
1SN 0278      283  XC=XC-50.
1SN 0279      GO TO 282
1SN 0280      284  I2=1
1SN 0281      DO 287 I=2,NX3
1SN 0282      IF(X3(I)-XC)285,285,286
1SN 0283      285  TH2(I2)=X3(I)
1SN 0284      ED2(I2)=DEN(I)
1SN 0285      I2=I+1
1SN 0286      XC=XC-50.
1SN 0287      GO TO 287

```

```
1SN 0268      286 IF(1-NX3)3#7,288,288
1SN 0289      287 CONTINUE
1SN 0290      288 TH2(12)=X3(1-NX3)
1SN 0291      ED2(12)=DEN(NX3)
1SN 0292      #RITE(6,753)
1SN 0293      WRITE(6,700)((TH2(I),ED2(I)),I=1,12)
1SN 0294      701 FORMAT(1H0,62H T. HGT. DEN. RESPECTIVELY (FIXED DENSITY INTERPOLATED))
1SN 0295      702 FORMAT(1H0,82H T. HGT. DEN. RESPECTIVELY (SCALED AND INTERPOLATED VALUES AT FIXED HEIGHTS))
1SN 0296      703 FORMAT(1H0,69H T. HGT. DEN. RESPECTIVELY (INTERPOLATED AT FIXED HEIGHTS ONLY))
1SN 0297      GO TO 100
1SN 0298      6000 STOP
1SN 0299      END
```



```

      COMPILER OPTIONS - NAME= MAIN,OPT=00,LINFCNT=56,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NJEDIT,IO,NOXREF
      10002      SUBROUTINE FIXIT(X,Y,XX,XINT,XMAX,XX,VV,NXX,IFLAG,METHOD,AA,BB)
      10003      IMPLICIT REAL*8(A-H,O-Z)
      10004      DIMENSION X(1),Y(1),XX(1),YY(1),AA(1),BB(1)
      10005      IFLAG=0
      10006      XK=XMAX
      10007      1 IF (XK-X(1))3,2,2
      10008      2 XK=XK-XINT
      10009      IF (XK)14,14,1
      10010      3 XX(1)=X(1)
      10011      YY(1)=Y(1)
      10012      PT1=X(1)
      10013      J=2
      10014      DO 90 I=2,NX
      10015      PT2=X(I)
      10016      IF (PT2-PT1)10,11,11
      10017      10 IF (PT2-XK)13,12,11
      10018      11 PT1=PT2
      10019      XX(J)=X(I)
      10020      YY(J)=Y(I)
      10021      J=J+1
      10022      GO TO 90
      10023      12 XK=XK-XINT
      10024      IF (XK)14,14,11
      10025      13 XX(J)=XK
      10026      IF (METHOD-1)20,20,21
      10027      20 YY(I)=Y(I)+(XX(J)-PT2)*(Y(I-1)-Y(I))/(PT1-PT2)
      10028      GO TO 22
      10029      21 DEL = BB(1)+BB(1)-0.01
      10030      IF (DEL)21,20,22
      10031      22 YY(J)= Y(I-1)+(-AA(1)-DSORT(AA(1)+AA(1)-4.0*BB(1)*(PT1-XK)))/(2.0*
      10032      DEL)
      10033      23 J=J+1
      10034      24 XK=XK-XINT
      10035      IF (XK)14,14,10
      10036      25 CONTINUE
      10037      GO TO 15
      10038      14 WRITE(5,700)
      10039      WRITE(6,701)(X(I),I=1,NX)
      10040      WRITE(6,701)(Y(I),I=1,NX)
      10041      IFLAG=1
      10042      15 NXX=J-1
      10043      RETURN
      10044      700 FORMAT(1H ,65H BUN DATA TRUE HGT. AND ELECTRON DEN. FOLLOW//)
      10045      701 FORMAT(2F15.5)
      10046      END

```

IEF2651 SYS71120,T110453,RV000,LSJEJ002,CPJMOD PASSED
 IEF2651 VOL SER ND5= M2SCR3.
 IEF2651 SYS71120,T110453,RV000,LSJEJ002,R0000057 SYSCUT
 IEF2651 VOL SER ND5= M2SCF3.
 IEF2651 SYS71120,T110453,RV000,LSJEJ002,R0000058 DELETED
 IEF2651 VOL SER ND5= M2DRM1.
 IEF2651 SYS71120,T110453,RV000,LSJEJ002,R0000059 DELETED
 IEF2651 VOL SER ND5= M2DRM1.
 IEF2651 SYS71120,T110453,RV000,LSJEJ002,S0000060 SYSLIN
 IEF2651 VOL SER ND5= M2SCR3.
 IEF2651 SYS71120,T110453,RV000,LSJEJ002,S0000060 DELETED
 IEF2651 VOL SER ND5= M2SCR3.
 IEF2731 STEP /SOURCE / START 71120,1210
 IEF2741 STEP /SOURCE / STOP 71120,1215 CPU 00MIN 02,02SEC MAIN 288K LCS OK

- STEP 01 - STEP TIME = .03 MINSE(CPU= .03,IO= .05)
 IO IN RECS. DISKE 2.05,DRUM= .20,TAPE= .00,CELL= .00,OTHR= .00

// EXEC LINKG,REGION,GRP100K
 XXDEFault PAGE NOLK=200 00000100
 //LINK EXEC PGMLINK,IT,PARM=MAP,LIST,COND=(5,LT),REGION=PACK 00000200
 XXLOADLIB DD DSN=MMLOAD,DISP=SHR 00000300
 XXNEWLIB DD DUMMY 00000400
 XXSYSLIB DD DSN=SYS1.DUMMY,DISP=SHR 00000500
 XX DD DSN=SYS1.DUMMY,DISP=SHR 00000600
 XX DD DSN=SYS1.FORLIB,DISP=SHR 00000700
 XX DD DSN=SYS1.PLILIB,DISP=SHR 00000800
 XX DD DSN=SYS1.GSFCLIB,DISP=SHR 00000900
 XX DD DSN=SYS1.SPL,DISP=SHR 00001000
 XX DD DSN=SYS1.CDLIB,DISP=SHR,VOL=SER=2SYS2,UNIT=2314 00001100
 XXSYSLMOD DD DSN=6ALODMOD(GSFC),DISP=(NEW,PASS),UNIT=2314, X00001200
 XX SPACE=(3072,(ENBLK,20,1)),DCB=BLKSIZE=3072 00001300
 IEF631 SUBSTITUTION JCL = SPACE=(3072,(200,20,1)),DCB=BLKSIZE=3072
 XXSYSPRINT DD SYSOUT=A,DCB=(RECFM=FB,LRECL=121,BLKSIZE=3500) 00001400
 XXSYSLIB DD SPACE=(3072,(ENBLK,20)),UNIT=LINK 00001500
 IEF631 SUBSTITUTION JCL = SPACE=(3072,(200,20)),UNIT=LINK
 XXTAPELIB DD DUMMY,DISP=(OLD,KEEP),UNIT=(24000,DEFER),LABEL=(,RLP), X00001600
 XX DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200) 00001700
 XXSYSLIB DD DSN=6FORJDD,DISP=(OLD,DELETE),DCB=RECFM=FB 00001800
 XX DD DSN=6OBJECT 00001900
 //LINK,OBJECT DD *

IEF2361 ALLOC. FOR LSJEJ002 LINK
 IEF2371 331 ALLOCATED TO LEADLIB
 IEF2371 100 ALLOCATED TO SYSLIB
 IEF2371 100 ALLOCATED TO
 IEF2371 107 ALLOCATED TO
 IEF2371 116 ALLOCATED TO
 IEF2371 335 ALLOCATED TO
 IEF2371 335 ALLOCATED TO
 IEF2371 335 ALLOCATED TO
 IEF2371 334 ALLOCATED TO SYSLMOD
 IEF2371 334 ALLOCATED TO SYSPRINT
 IEF2371 333 ALLOCATED TO SYSUT1
 IEF2371 333 ALLOCATED TO SYSLIN
 IEF2371 334 ALLOCATED TO


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IEF285I MMLoad
IEF285I VOL SER NOS= M2LOAD.
IEF285I SYS1.DUMMY
IEF285I VOL SER NOS= M2DRM1.
IEF285I SYS1.DUMMY
IEF285I VOL SER NOS= M2DRM1.
IEF285I SYS1.FORTLTH
IEF285I VOL SER NOS= M2DRM1.
IEF285I SYS1.PL1LIB
IEF285I VOL SER NOS= M2SYS4.
IEF285I SYS1.GSPCLTH
IEF285I VOL SER NOS= M2SYS2.
IEF285I SYS1.SSP
IEF285I VOL SER NOS= M2SYS1.
IEF285I SYS1.CORLIB
IEF285I VOL SER NOS= M2SYS2.
IEF285I SYS71120.T110453.RV000.LEJEU002.LEDMOD PASSED
IEF285I VOL SER NOS= M2SCR6.
IEF285I SYS71120.T110453.SV000.LEJEU002.R0000061 SYSCUT
IEF285I VOL SER NOS= M2CR6.
IEF285I SYS71120.T110453.RV000.LEJEU002.R0000062 DELETED
IEF285I VOL SER NOS= M2SCR5.
IEF285I SYS71120.T110453.RV000.LEJEU002.OBJMOD DELETED
IEF285I VOL SER NOS= M2SCR5.
IEF285I SYS71120.T110453.RV000.LEJEU002.S0000063 SYSIN
IEF285I VOL SER NOS= M2SCR1.
IEF285I SYS71120.T110453.RV000.LEJEU002.S0000067 DELETED
IEF285I VOL SER NOS= M2SCR1.

```

```

IEF373I STEP /LINK / START 71120.1210
IEF374I STEP /LINK / STOP 71120.1210 CPU 00MIN 00.40SEC MAIN 154K LCS OK

```

```

- STEP 02 -
          IQ IN SECS, DIRX= 9.25, DRUM= 2.08, TAPE= .18 MIN5=(CPU= .00, TOR= .18)
          STEP TIME = .00, CELL= .00, OTHER= .00

```

```

XXG0 EXEC PGM=,LINK,SYSLMOD,CMD=(SYLT),REGION=100 00002000
XXFTCEFP001 DD DDNAME=DATA 00002100
XXFTCFEP001 DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=7265) 00002200
XXFTCFEP001 DD DUMMY,DCB=(RECFM=FB,LRECL=80,BLKSIZE=3200) X00002300
XX* TO GET A DECK, ADD THE FOLLOWING CARD TO YOUR DECK X00002400
XX* //GO,FT07P001 DD DDNAME=DECK,SYSPUT=8 00002500
XXSYSPRINT DD SYSOUT=A,DCB=(RECFM=VBA,LRECL=137,BLKSIZE=7265) 00002600
//GO,DATA DD *
//

```

```

IEF235I ALLOC. FOR LEJEU002 GO
IEF237I 334 ALLOCATED TO PGM=,DD
IEF237I 232 ALLOCATED TO FT05P001
IEF237I 332 ALLOCATED TO FT06P001
IEF237I 333 ALLOCATED TO SYSPRINT

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SEPT. 65 COEFFICIENTS

-60.00	-180.00	100.0	1940.0	9820.0102	7857.0808	-50621.6289	61913.9951
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REFERENCE DENSITIES FOR INTERPOLATION

[illegible]

748.7	0.468584D	05	723.9	0.515673D	05	700.0	0.569037D	05	681.3	0.617365D	05	650.0	0.710039D	05	644.2	0.728812D	05
611.6	0.550030D	05	600.0	0.590910D	05	583.2	0.5961168D	05	558.0	0.6112218D	06	550.0	0.6117396D	06	535.8	0.6127314D	06
500.0	0.6157123D	06	487.5	0.6169308D	06	480.0	0.6211571D	06	445.4	0.6217297D	06	409.6	0.6271380D	06	400.0	0.6269036D	06
378.8	0.6331581D	06	350.0	0.6337577D	06	349.0	0.6397782D	06	322.1	0.6469954D	06	300.0	0.6520835D	06	286.1	0.647832D	06
280.1	0.656997D	06	275.4	0.663365D	06	243.1	0.670890D	06									

T. HGT. DEN. RESPECTIVELY (INTERPOLATED AT FIXED HEIGHTS ONLY)

1000.0	0.211261D	05	950.0	0.245942D	05	900.0	0.282496D	05	850.0	0.327313D	05	800.0	0.386995D	05	750.0	0.466500D	05
700.0	0.569037D	05	650.0	0.710039D	05	600.0	0.900910D	05	550.0	0.6117396D	06	500.0	0.6157123D	06	450.0	0.611571D	06
400.0	0.6269036D	06	350.0	0.6337577D	06	300.0	0.6520835D	06	263.1	0.670890D	06						

T. HGT. DEN. RESPECTIVELY (SCALED AND INTERPOLATED VALUES AT FIXED HEIGHTS)


```

C      METHOD 1=LINEAR IN LOG N, METHOD 2=PARABOLIC IN LOG N
ISN 0035 101  FORMAT(4I10)
ISN 0036      READ(5,103)  HT,DIP,FHS,DLAT,DLONG
ISN 0037      READ (5,103) (HP(I),F(I),I=1,N)
ISN 0038 104  FORMAT (8F10.4)
ISN 0039      WRITE (6,3011) TITLE
ISN 0040 3011  FORMAT (1H1,5X,20A4/1H ,5X,20A4)
ISN 0041      IF(METHOD-1)500,500,501
ISN 0042 500  WRITE(6,502)
ISN 0043 502  FORMAT(1H0,25HFIELD G ,LINEAR IN LOG(N))
ISN 0044      GO TO 503
ISN 0045 501  WRITE(6,504)
ISN 0046 504  FORMAT(1H0,27HFIELD G,PARABOLIC IN LOG(N))
ISN 0047      WRITE(6,803)
ISN 0048 803  FORMAT(1H0,10HINPUT DATA)
ISN 0049 503  WRITE (6,104) IYR,IDY,ITI
ISN 0050 104  FORMAT(1H0,6HYEAR 19I2,6X,3HDAYI4,6X,4HTIMEI7)
ISN 0051      WRITE (6,2114)
ISN 0052 2114  FORMAT(1H0,47HLOCATION FROM WORLD MAP, ESTIMATED DIP AND FHS.)
ISN 0053      WRITE (6,105) HT,DIP,FHS,DLAT,DLONG
ISN 0054 105  FORMAT (1H ,3HHT=F10.4,5X,4HDIP=F10.4,5X,4HFHS=F10.4,5X,5HDLAT=F10
1.4,5X,6HDLONG=F10.4)
ISN 0055 2002  WRITE (6,2005)
ISN 0056 2005  FORMAT (1H0,7HX TRACE)
ISN 0057      WRITE (6,106)
ISN 0058 106  FORMAT(1H ,9(3X,1HF,6X,2HHP,2X))
ISN 0059      WRITE(6,107)(F(I),HP(I),I=1,N)
ISN 0060 107  FORMAT(9(1X,F6.3,1X,F6.1))

C
C      USE FIELDG TO COMPUTE FH AT SATELLITE AND DIP, IN PLACE OF VALUES
C      READ IN ON DATA CARDS. IF FIELDG NOT AVAILABLE, OMIT THIS CALL.
ISN 0061      CALL FIELDG(DLAT,DLONG,HT,DATE,20,LO,BN,BE,BV,BT)
ISN 0062      FT = BT
ISN 0063      FV = BV
ISN 0064      HH =DSQRT(FT**2 - FV**2)
ISN 0065      BVH = BV/HH
ISN 0066      DIP =DATAN(BVH)*57.29578
ISN 0067      FH(1)=BT*2.8000E-05
ISN 0068      FHS = FH(1)
ISN 0069      WRITE (6,2115)
ISN 0070 2115  FORMAT(1H0,72HLOCATION FROM WORLD MAP, DIP AND FHS AT SATELLITE CO
IMPUTED FROM FIELD G.)
ISN 0071      WRITE (6,105) HT,DIP,FHS,DLAT,DLONG

C
ISN 0072      DIP =DSQRT(DIP*DIP)
ISN 0073      WRITE (6,108)
ISN 0074 108  FORMAT (1H0,6X,1HF,16X,4HELCC,14X,6HHEIGHT,4X,9HITERATION,8X,2HFI,
111X,12HPREVIOUS HGT,9X,5HSL OPE)
ISN 0075      A=(90.0-DIP)/57.29577
ISN 0076      CPH=DCOS(A)
ISN 0077 2007  FH(1) = FHS
ISN 0078      TH(1) = HT
ISN 0079      TEST=FH(1)+0.001
ISN 0080      FREQ = F(1)
C      EXT. RAY EXIT FREQ. MUST BE GREATER THAN FHS
ISN 0081      IF (FREQ - 15.0 ) 4000,9,9

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```

LSN 0082      4000 IF (FREQ - TEST ) 9,10,10
LSN 0083      9  F(I) = TEST
LSN 0084      I = 1
LSN 0085      METHOD = 1
LSN 0086      WRITE(6,13)I
LSN 0087      13  FORMAT(1H ,46HFREQUENCY READ TOO LOW ON INPUT DATA POINT NO,12,2X,
154H/PROGRAM IS LINEAR IN LOG(N) FOR REMAINDER OF IONOGRAM)
LSN 0088      10  DEN(I)=(F(I)*(F(I)-FH(I)))*12400.0
LSN 0089      ELCC = DEN(I)
LSN 0090      FA = F(I)
LSN 0091      NL = N
LSN 0092      WRITE(6,173)FA,ELCC,HT
LSN 0093      173 FORMAT(1H0,F12.4,6X,F12.4,6X,F12.4)
LSN 0094      FH(I) = FHS
LSN 0095      DO 20 I=2,N
LSN 0096      15  DP = 0.0
LSN 0097      IO = 0
LSN 0098      IF(I-NL)8,8,20
LSN 0099      8  TEST = F(I-1) + 0.001
LSN 0100      FREQ = F(I)
LSN 0101      IF(FREQ-TEST)29,12,12
LSN 0102      29  NL = NL-1
LSN 0103      FA = F(I)
LSN 0104      METHOD = 1
C      BAD DATA POINTS ARE REJECTED IN DO 33
LSN 0105      DO 33 L=1,NL
LSN 0106      HP(L) = HP(L+1)
LSN 0107      33  F(L) = F(L+1)
LSN 0108      WRITE(6,11)FA
LSN 0109      11  FORMAT(1H , 11HDATA FOR F=F6,3,2X,17HHAS BEEN REJECTED)
LSN 0110      GO TO 15
C      INITIAL FH(I) BASED UPON 0.1 PER CENT INCREASE IN DENSITY
LSN 0111      12  FH(I) = F(I) - (F(I-1)*(F(I-1)-FH(I-1)))/(0.999*F(I))
LSN 0112      AAA = 1.15*FH(I-1) - FH(I)
LSN 0113      IF(AAA)900,901,901
LSN 0114      900 FH(I) = 1.15*FH(I-1)
LSN 0115      901 GIRD = FH(I)
LSN 0116      TH(I) = TH(I-1)
LSN 0117      HGT = TH(I-1)
LSN 0118      FA = F(I)
LSN 0119      FAFA = FA*FA
LSN 0120      M = 2
C      YR=Y AT REFLECTION POINT
LSN 0121      14  YR = FH(I)/FA
LSN 0122      HGTA = TH(I)
LSN 0123      GYRO = FH(I)
LSN 0124      DO 24 J=M,1
LSN 0125      F1F1=F(J-1)*(F(J-1)-FH(J-1))
LSN 0126      F2F2=F(J)*(F(J)-FH(J))
LSN 0127      Y1 = FH(J-1)/FA
LSN 0128      Y2 = FH(J)/FA
LSN 0129      X1 = F1F1/FAFA
LSN 0130      X2 = F2F2/FAFA
C      CHANGE FROM VARIABLE X TO VARIABLE T
LSN 0131      T1=DSORT(1.0-(X1/(1.0-YR)))
LSN 0132      S1 = 0.0

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ISN 0133      S2=0.0
C             B9 AND C9 ARE USED IN FORMULA TO CHANGE Y WITHIN LAMINATION
ISN 0134      B9 = DLOG(Y2/Y1)/3.0
ISN 0135      V=DLOG(X2/X1)
ISN 0136      IF (J-1) 19,19,18
ISN 0137      18  T2 = 0.0
ISN 0138      IF(METHOD-1)151,151,506
ISN 0139      506 IF(1-2)151,151,155
ISN 0140      155 IF(10-2)151,152,152
ISN 0141      151 ALIM = 1.0
ISN 0142      RA = 1.0
ISN 0143      RR = 0.0
ISN 0144      GO TO 156
ISN 0145      152 AA(I) = AA1
ISN 0146      153 BB(I) = (TH(I)-TH(I-1)-AA(I)*V)/(V*V)
ISN 0147      AA(I+1)=AA(I)+(2.0)*BB(I)*V
ISN 0148      ALIM = AA(I+1)/AA(I)
ISN 0149      GO TO 154
ISN 0150      19 T2=DSQRT(1.0-(X2/(1.0-YR)))
ISN 0151      IF(METHOD-1)151,151,508
ISN 0152      508 ALIM = 1.0
ISN 0153      154 RB = BB(J)/AA(J)
ISN 0154      RA = 1.0+RB*V
ISN 0155      156 C9 =(DEXN(B9)-1.0)/(V*RA)
C             GAUSSIAN INTEGRATION
ISN 0156      20 DO 605 K=1,3
ISN 0157      T = 0.5*((T1-T2)*SS(K)+T1+T2)
ISN 0158      X=(1.0-T*T)*(1.0-YR)
ISN 0159      A = DLOG(X2/X)
ISN 0160      Y = Y2/((1.0+C9*A*(1.0+RB*(2.0*V-A)))*3)
ISN 0161      IF (I-0.0002) 601,601,602
ISN 0162      601 Y = YR
C             UX IS VALUE OF INTEGRAND AT THE REFLECTION POINT
ISN 0163      UX=(0.707107*((2.0-Y)/(1.0-Y))*((1.0/DSQRT(1.0+CPH*CPH)))
      U /((1.0-Y)*DSQRT(1.0+(3.0*C9*Y*ALIM)/(1.0-Y)))
ISN 0164      GO TO 603
ISN 0165      602 YL = Y * CPH
ISN 0166      YT2 = Y*Y*(1.0-CPH*CPH)
ISN 0167      IF(CPH-0.0009) 608,604,604
ISN 0168      604 R = YT2/(2.0*YL)
ISN 0169      R = R/(1.0-X)
ISN 0170      PSI=DATAN(R)
ISN 0171      A=(1.0+DSIN(PSI))*DSQRT(1.0+R*R)
ISN 0172      SX = 1.0-A*YL
ISN 0173      GO TO 609
ISN 0174      608 PSI = 1.57079
ISN 0175      SX = 1.0 - (Y*Y)/(1.0-X)
ISN 0176      609 B = X/SX
ISN 0177      IF(0.999990 -B)29,29,612
C             REJECTS BAD DATA CARDS
ISN 0178      612 U =DSQRT (1.0-B)
ISN 0179      C = (1.0-SX)/(2.0*SX)
ISN 0180      D=1.0+(1.0*X)*DSIN(PSI)/(1.0-X)
ISN 0181      UP = (1.0 + B*C*D)/U
ISN 0182      UX =(UP * T)/X
ISN 0183      603 S1 = S1+UX*W(K)

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ISN 0184      UX2=UX*DLUG(X/X1)
ISN 0185      S2=S2+UX2*W(K)
ISN 0186      605 CONTINUE
ISN 0187      SA=S1*(T1-T2)*0.5
ISN 0188      ASUM=2.0*(1.0-YR)*SA
ISN 0189      SB=52*(T1-T2)*0.5
ISN 0190      BSUM=4.0*(1.0-YR)*SB
ISN 0191      IF(J-1) 23,25,25
ISN 0192      23 DP=DP-AA(J)*ASUM-BB(J)*BSUM
ISN 0193      24 CONTINUE
ISN 0194      25 IF(I-2) 60,60,61
ISN 0195      60 AA(2)=-HP(2)/ASUM
ISN 0196      TH(2)=TH(1)+AA(2)*DLOG(X2/X1)
ISN 0197      AAI = AA(2)
ISN 0198      GO TO 62
ISN 0199      61 IF(METHOD-1)70,70,510
ISN 0200      510 IF(IQ-2)70,71,71
ISN 0201      70 AH=(DP-HP(I))/ASUM
ISN 0202      TH(I)=TH(I-1)+AH*DLOG(X2/X1)
ISN 0203      AA(I)=AH
ISN 0204      BB(I)=0.0
ISN 0205      HGT=TH(I)
ISN 0206      IF(METHOD-1)62,62,27
ISN 0207      71 BBII =(DP-AA(I)*ASUM-HP(I))/BSUM
ISN 0208      V=DLOG(X2/X1)
ISN 0209      TH(I)=TH(I-1)+AA(I)*V+BBII *V*V
ISN 0210      BB(I) = BBII
ISN 0211      62 HGT =TH(I)
ISN 0212      C      CONVERGENCE TEST TO INSURE THAT SUCCESSIVE HT. ARE WITHIN 0.01 KM
ISN 0213      A = HGT-HGTA
ISN 0214      A = 0.0001- A*A
ISN 0215      IF(A) 27,30,30
ISN 0216      27 IQ = IQ+1
ISN 0217      M=I
ISN 0217      C      ITERATE ONLY FOR LAST LAMINATION (M=1),10 ITERATIONS MAX. NO.
ISN 0217      IF(IQ-9)66,66,30
ISN 0217      C
ISN 0217      C      USE FIELDG TO COMPUTE FH AT ITH POINT. IF NOT AVAILABLE, REPLACE
ISN 0217      C      THIS CALL WITH THE FOLLOWING INVERSE-CUBE APPROXIMATION:
ISN 0217      C      FH(I)=FHS*(((6371.0+HT)/(6371.0+HGT(I)))**3)
ISN 0217      C
ISN 0217      C      WHERE HT=SATELLITE HEIGHT.
ISN 0218      66 CALL FIELD GDLAT,DLONG,HGT,DATE,20,LQ,BN,BE,BV,BT)
ISN 0219      FH(I)=BT*2.8000E-05
ISN 0220      GYRO = FH(I)
ISN 0221      DEN(I)=(F(I))*(F(I)-FH(I))*12*00,0
ISN 0222      ELCC = DEN(I)
ISN 0223      A = DEN(I) - DEN(I-1)*1.001
ISN 0224      C      IF DENSITY DOES NOT INCREASE BY AT LEAST 0.1 PER CENT,REJECT PT
ISN 0224      IF(A)29,14,14
ISN 0225      30 V = DLOG(X2/X1)
ISN 0226      AAI = AAI+(2.0)*BB(I)*V
ISN 0227      WRITE(6,172)FA,ELCC,HST,10,GYRO,HGTA,AAI
ISN 0228      172 FORMAT(1H ,F12.5,6X,F12.4,6X,F12.4,6X,I2,6X,F12.6,6X,F12.4,6X,
ISN 0228      IF12.4)
ISN 0229      28 CONTINUE
ISN 0229      C      INTERPOLATION ROUTINE

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ISN 0230      N = NL
ISN 0231      DO 260 I=1,N
ISN 0232      280 DENL(I) = DLOG(DEN(I))
ISN 0233      N=N-1
ISN 0234      M=1
ISN 0235      K=1
ISN 0236      DO 816 L=1,N
ISN 0237      K=K-1
ISN 0238      D2A = DEN(L)
ISN 0239      D2B = DEN(L+1)
ISN 0240      Z2A = TH(L)
ISN 0241      Z2B = TH(L+1)
ISN 0242      H = (Z2B-Z2A)/(DEN(L+1)-DEN(L))
ISN 0243      810 K=K+1
ISN 0244      D1 = DENREF(K)
ISN 0245      IF(D1-D2A)810,812,813
ISN 0246      812 DENINT(M) = D1
ISN 0247      ZINT(M) = Z2A
ISN 0248      M=M+1
ISN 0249      GO TO 810
ISN 0250      813 IF(D1-D2B)814,815,816
ISN 0251      814 DENINT(M) = D1
ISN 0252      IF(METHOD-1)817,817,819
ISN 0253      817 ZINT(M) = Z2A+(ALOG(D1)-DENL(L))*H
ISN 0254      M=M+1
ISN 0255      GO TO 810
ISN 0256      819 V = DLOG(D1/D2A)
ISN 0257      ZINT(M)=Z2A+AA(L+1)*V+BB(L+1)*V*V
ISN 0258      M=M+1
ISN 0259      GO TO 810
ISN 0260      815 DENINT(M)=D1
ISN 0261      ZINT(M)=Z2B
ISN 0262      M=M+1
ISN 0263      816 CONTINUE
ISN 0264      MM=M-1
ISN 0265      WRITE(6,701)
ISN 0266      WRITE(6,700)(ZINT(M),DENINT(M),M=1,MM)
ISN 0267      N = N + 1
ISN 0268      XMAX = 3000.
ISN 0269      GGG = 50.0
ISN 0270      CALL FIXIT (TH,DENL,N,GGG,XMAX,X3,Y3,NX3,IFLAG,METHOD,AA,BB)
ISN 0271      DO 281 I=1,NX3
ISN 0272      281 DEN(I) =DEXP(Y3(I))
ISN 0273      WRITE(6,702)
ISN 0274      WRITE (6,700)(X3(I),DEN(I), I=1,NX3)
ISN 0275      700 FORMAT(6(2X,F6.1,E13.6))
ISN 0276      XC=3000.
ISN 0277      282 IF(X3(I)-XC)283,283,284
ISN 0278      283 XC=XC-50.
ISN 0279      GO TO 282
ISN 0280      284 I2=1
ISN 0281      DO 287 I=2,NX3
ISN 0282      IF(X3(I)-XC)286,285,286
ISN 0283      285 TH2(I)=X3(I)
ISN 0284      ED2(I2)=DEN(I)
ISN 0285      I2=I2+1

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```
ISN 0286      XC=XC-50.  
ISN 0287      GO TO 287  
ISN 0288      285  IF(I-NX3)287,288,288  
ISN 0289      287  CONTINUE  
ISN 0290      288  TH2(I2)=X3(NX3)  
ISN 0291      ED2(I2)=DEN(NX3)  
ISN 0292      WRITE(6,703)  
ISN 0293      WRITE(6,700)(TH2(I),ED2(I),I=1,12)  
ISN 0294      701  FORMAT(1H0,62H  I. HGT.  DEN.  RESPECTIVELY  (FIXED DENSITY INTE  
IRPOLATION))  
ISN 0295      702  FORMAT(1H0,82H  I. HGT.  DEN.  RESPECTIVELY  (SCALED AND INTERPO  
LATED VALUES AT FIXED HEIGHTS))  
ISN 0296      703  FORMAT(1H0,69H  I. HGT.  DEN.  RESPECTIVELY  (INTERPOLATED AT FI  
XED HEIGHTS ONLY))  
ISN 0297      GO TO 100  
ISN 0298      6000 STOP  
ISN 0299      END
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```

COMPILER OPTIONS = NAME= MAIN,OPT=00,LINECNT=58,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NODEDIT,LD,XREF
ISN 0002 SUBROUTINE FIXIT(X,Y,NX,XINT,XMAX,XX,YY,NXX,IFLAG,METHOD,AA,BB)
ISN 0003 IMPLICIT REAL*8(A-H,O-Z)
ISN 0004 DIMENSION X(1),Y(1),XX(1),YY(1),AA(1),BB(1)
ISN 0005 IFLAG=0
ISN 0006 XK=XMAX
ISN 0007 1 IF(XK-X(1))3,2,2
ISN 0008 2 XK=XK-XINT
ISN 0009 IF(XK)14,14,1
ISN 0010 3 XX(1)=X(1)
ISN 0011 YY(1)=Y(1)
ISN 0012 PT1=X(1)
ISN 0013 J=2
ISN 0014 DO 90 I=2,NX
ISN 0015 PT2=X(I)
ISN 0016 IF(PT2-PT1)10,11,11
ISN 0017 10 IF(PT2-XK)13,12,11
ISN 0018 11 PT1=PT2
ISN 0019 XX(J)=X(I)
ISN 0020 YY(J)=Y(I)
ISN 0021 J=J+1
ISN 0022 GO TO 90
ISN 0023 12 XK=XK-XINT
ISN 0024 IF(XK)14,14,11
ISN 0025 13 XX(J)=XK
ISN 0026 IF (METHOD-1)20,20,21
ISN 0027 20 YY(J)=Y(I)+((XX(J)-PT2)*(Y(I-1)-Y(I))/(PT1-PT2)
ISN 0028 GO TO 22
ISN 0029 21 DEL = BB(I)*BB(I)-0.01
ISN 0030 IF(DEL)20,20,23
ISN 0031 23 YY(J)= Y(I-1)+(-AA(I)-DSQRT(AA(I)*AA(I)-4.0*BB(I)*(PT1-XK)))/(2.0*
1BB(I))
ISN 0032 22 J=J+1
ISN 0033 XK=XK-XINT
ISN 0034 IF(XK)14,14,10
ISN 0035 90 CONTINUE
ISN 0036 GO TO 15
ISN 0037 14 WRITE(6,700)
ISN 0038 WRITE(6,701)(X(I),I=1,NX)
ISN 0039 WRITE(6,701)(Y(I),I=1,NX)
ISN 0040 IFLAG=1
ISN 0041 NXX=J-1
ISN 0042 RETURN
ISN 0043 700 FORMAT(1H,4BH BUM DATA TRUE HGT. AND ELECTRON DEN. FOLLOW//)
ISN 0044 701 FORMAT(8E15.5)
ISN 0045 END

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COMPILER OPTIONS - NAME= MAIN,OPT=00,LINECNT=58,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NODEDIT,10,XREF
ISN 0002 SUBROUTINE FIELDG (DLAT,DLONG,ALT,TM,NMX,L,X,Y,Z,F) 1
ISN 0003 EQUIVALENCE (SHMIT,TG) 2
ISN 0004 COMMON/FLDCOM/ST,CT,SPH,CPH,R,DT,BP,BR,B,NMAX 3
ISN 0005 COMMON /COEFFS/TG(18,18) 5
ISN 0006 DIMENSION G(18,18),GT(18,18),SHMIT(18,18),AID(15)
ISN 0007 IF (AEO,6378.165) IF(L)19,1,2
ISN 0009 DATA MAXN,TZERO,J,K/10,1960.,0.0/,G/ 1
X0,0,-30424.9,-1536.1,1300.9,957.6,-227.7,49.8,70.9,4.8,9.9,8*0.,57 2
X74,8,-2161.6,3000.2,-1987.0,802.8,359.5,60.7,-57.2,6.7,2.9,8*0.,-1 3
X949.8,204.3,1585.3,1290.4,502.6,231.3,4.5,5.6,-8.8,7.8,8*0.,-431.0 4
X1230.8,-130.0,871.2,-394.0,-31.2,-241.7,7.5,-13.8,-15.6,8*0.,152.0 5
X1-268.4,2.9,-250.5,271.4,-157.3,-1.2,-24.4,-3.3,11.4,8*0.,85.121. 6
X2,-116.0,-110.4,79.9,-65.2,0.5,-1.5,7.1,11.1,8*0.,-11.9,102.8,60.9 7
X1-27.2,-12.4,-11.0,-109.1,14.1,-5.6,1.8*0.,-54.,-24.4,-9.1,2.2,27 8
X1,6,-21.1,-20.1,5.8,11.7, 9*0.,5.9,-12.2,5.8,-17.0,2.6,23.6,-2.5,-1 9
X0,0,6.4,1.6,8*0.,-22.0,15.6,5.1,-3.5,-1.8,9.6,12.1,0.2,-2.5,1.5,15 10
X2*0./ 11
ISN 0010 DATA GT/ 1
X0,0,20.59,-29.07,2.66,-0.86,2.55,-0.70,11*0.,-3.94,6.02,1.21,-10.0 2
X3,1.94,-0.08,0.99,1140.,-13.69,-15.78,-0.70,1.63,-1.17,1.53,0.85,1 3
X1*0.,0.49,2.93,-9.24,-1.30,-0.54,-0.43,2.11,11*0.,1.77,-1.54,3.18, 4
X-5.48,-4.17,-0.72,1.57,11*0.,3.04,2.88,-1.86,1.25,0.80,1.64,-0.09, 5
X11*0.,-1.39,0.12,1.53,-0.73,-0.06,0.45,0.06,209*0, / 6
ISN 0011 A=6378.165 44
ISN 0012 FLAT=1.-1./298.3 45
ISN 0013 A2=A**2 46
ISN 0014 A4=A**4 47
ISN 0015 B2=(A*FLAT)**2 48
ISN 0016 A2B2=A2*(1.-FLAT**2) 49
ISN 0017 A4B4=A4*(1.-FLAT**4) 50
ISN 0018 IF (L)14,14,2
ISN 0019 1 IF (TM-TLAST) 17,19,17 52
ISN 0020 2 READ (5,3) J,K,TZERO,AID * 53
ISN 0021 3 FORMAT (2I1,1X,F6.1,15A4,A3) 54
ISN 0022 L=0 55
ISN 0023 WRITE (6,4) J,K,TZERO,AID * 56
ISN 0024 4 FORMAT (2I3,5X6EPOCH=F,7.1,5X15A4,A3) 58
ISN 0025 MAXN=0 59
ISN 0026 TEMP=0. 60
ISN 0027 5 READ (5,6) N1,M,GNM,HNM,GINM,HTNM 62
ISN 0028 6 FORMAT(2I3,6F11.4) 62
ISN 0029 IF (N1.LE.0) GOTO7 63
ISN 0031 MAXN=(MAX0(N1,MAXN))
ISN 0032 G(N,M)=GNM 65
ISN 0033 GT(N,M)=GTNM
ISN 0034 TEMP= MAX1(TEMP, ABS(GTNM)) 67
ISN 0035 IF (M.EV.1) GOTO5
ISN 0037 G(M-1,N)=HNM 59
ISN 0038 GT(M-1,N)=HTNM 70
ISN 0039 GO TO 5 71
ISN 0040 7 WRITE (6,8) 71
ISN 0041 8 FORMAT (6H0 N M,6X1HG,10X1HH,9X2HGT,9X2HHT//) 72
ISN 0042 DD 12 N=2,MAXN 73
ISN 0043 DD 12 M=1,N 74

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ISN 0044		MI=M-1	75
ISN 0045		IF (M.EQ.1) GOTO10	76
ISN 0047		WRITE (6,9) N,M,G(N,M),G(MI,N),GT(N,M),GT(MI,N)	77
ISN 0048	9	FORMAT (2I3,4F11.4)	78
ISN 0049		GO TO 12	79
ISN 0050	10	WRITE (6,11) N,M,G(N,M),GT(N,M)	80
ISN 0051	11	FORMAT (2I3,4F11.4,11X,F11.4)	81
ISN 0052	12	CONTINUE	82
ISN 0053		WRITE (6,13)	83
ISN 0054	13	FORMAT (1H1)	84
ISN 0055		IF (TEMP.EQ.0.) L=-1	85
ISN 0057	14	IF (K.NE.0) GOTO17	86
ISN 0059		SHMIT(1,1)=-1.	87
ISN 0060		DO 15 N=2,MAXN	88
ISN 0061		SHMIT(N,1)=SHMIT(N-1,1)*FLOAT(2*N-3)/FLOAT(N-1)	89
ISN 0062		SHMIT(1,N)=0.	90
ISN 0063		JJ=2	91
ISN 0064		DO 15 M=2,N	92
ISN 0065		SHMIT(N,M)=SHMIT(N,M-1)*SQRT(FLOAT((N-M+1)*JJ)/FLOAT(N+M-2))	93
ISN 0066		SHMIT(M-1,N)=SHMIT(N,M)	94
ISN 0067	15	JJ=1	95
ISN 0068		DO 16 N=2,MAXN	96
ISN 0069		DO 16 M=1,N	97
ISN 0070		G(N,M)=G(N,M)*SHMIT(N,M)	98
ISN 0071		GT(N,M)=GT(N,M)*SHMIT(N,M)	99
ISN 0072		IF (M.EQ.1) GOTO16	100
ISN 0074		G(M-1,N)=G(M-1,N)*SHMIT(M-1,N)	101
ISN 0075		GT(M-1,N)=GT(M-1,N)*SHMIT(M-1,N)	
ISN 0076	16	CONTINUE	103
ISN 0077	17	T=TM-TZERO	104
ISN 0078		DO 18 N=1,MAXN	105
ISN 0079		DO 18 M=1,N	106
ISN 0080		TG(N,M)=G(N,M)+T*GT(N,M)	107
ISN 0081		IF (M.EQ.1) GOTO18	108
ISN 0083		TG(M-1,N)=G(M-1,N)+T*GT(M-1,N)	109
ISN 0084	18	CONTINUE	110
ISN 0085		TLAST=TM	
ISN 0086	19	SINLA= SIN(PLAT/57.29578)	
ISN 0087		RLONG=DLONG/57.29578	
ISN 0088		CPH= COS(RLONG)	
ISN 0089		SPH= SIN(RLONG)	
ISN 0090		IF (J.EQ.0) GOTO20	115
ISN 0092		R=ALT+6371.2	116
ISN 0093		CT=SINLA	117
ISN 0094		GO TO 21	118
ISN 0095	20	SINLA2=SINLA**2	119
ISN 0096		COSLA2=1.-SINLA2	120
ISN 0097		DEN2=A2-A2B2*SINLA2	121
ISN 0098		DEN= SQRT(DEN2)	
ISN 0099		FAC=((ALT*DEN)+A2)/((ALT*DEN)+B2)**2	123
ISN 0100		CT=SINLA/ SQRT(FAC*COSLA2+SINLA2)	
ISN 0101		R= SQRT(ALT*(ALT+2.*DEN)+(A4-A4B4*SINLA2)/DEN2)	
ISN 0102	21	ST= SQRT(1.-CT**2)	
ISN 0103		NMAX=MINO(NMX,MAXN)	127
ISN 0104		CALL FIELD	128
ISN 0105		Y=BP	

ISN 0106		F=B	129
ISN 0107		IF (J) 22,23,22	130
ISN 0108	22	X=-BT	131
ISN 0109		Z=-BR	132
ISN 0110		RETURN	133
	C	TRANSFORMS FIELD TO GEODETIC DIRECTIONS	
ISN 0111	23	SIND=SINLA*ST- SQRT(COSLA2)*CT	
ISN 0112		COSD= SQRT(1.0-SIND**2)	136
ISN 0113		X=-BT*COSD-BR*SIND	137
ISN 0114		Z=BT*SIND-BR*COSD	138
ISN 0115		RETURN	
ISN 0116		END	

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COMPILER OPTIONS = NAME= MAIN,OPT=00,LINECNT=58,SOURCE,EBCDIC,NOLIST,NODECK,LOAD,MAP,NOEDIT,NOXREF
ISN 0002 IMPLICIT REAL*8(A-H,C-Z)
ISN 0003 REAL*8 DIAT,DLONG,HT,DATE,HGT,BN,BF,EV,BT
ISN 0004 COMMON /BLK1/ PEN(100),TH(100),AA(100),AA1,RATIO,HMAX,DMAX,N
ISN 0005 DIMENSION HP(100),F(100),SS(20),W(20),FH(100),DENL(200),X3(200),Y3
2(200),TH2(200),ED2(200),RB(100),HINT(40),CINT(40),STDD(2),STDCV(2),
2DENREF( 84),DENINT(200),ZINT(200),HPA(50),HPX(100),FX(100),TITLE(4
30),HPH(50),HPXD(50),FXD(50),DIFF(50),FZ(50),HPXX(50),HPAP(100)
ISN 0006 DATA DENREF/1.E4,2.E4,3.E4,4.E4,5.E4,6.E4,7.E4,8.E4,9.E4,1.0E5,
D 1.1E5,1.2E5,1.3E5,1.4E5,1.5E5,1.6E5,1.7E5,1.8E5,1.9E5,2.0E5,
D 2.1E5,2.2E5,2.3E5,2.4E5,2.5E5,2.6E5,2.7E5,2.8E5,2.9E5,3.0E5,
D 3.2E5,3.4E5,3.6E5,3.8E5,4.0E5,4.2E5,4.4E5,4.6E5,4.8E5,5.0E5,
D 5.2E5,5.4E5,5.6E5,5.8E5,6.0E5,6.2E5,6.4E5,6.6E5,6.8E5,7.0E5,
D 7.2E5,7.4E5,7.6E5,7.8E5,8.0E5,8.2E5,8.4E5,8.6E5,8.8E5,9.0E5,9.2E5,9.4E5,9.6E5,9.8E5,1.0E6,1.1E6,
D 1.2E6,1.3E6,1.4E6,1.5E6,1.6E6,1.7E6,1.8E6,1.9E6,2.0E6,2.2E6,
D 2.4E6,2.6E6,2.8E6,3.0E6,3.2E6,3.4E6,3.6E6,3.8E6,4.0E6,4.2E6,
D 4.4E6,4.6E6,4.8E6,5.0E6/
C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC
C C
C PROGRAM PROVIDED TO NATIONAL SPACE SCIENCE DATA CENTER, NASA/GSFC, BY
C J.E. JACKSON ON 5 MAY 1971.
C C GROUND ANALYSIS BASED ON TOPSIDE PROGRAM. C
C C ORDINARY POINTS ARE SCALED FOR INPUT, AND 10 X POINTS. THE C
C C COMPUTED X-TRACE IS INPUT TO TAB AND THE RESULTING CURVE IS C
C C INTERPOLATED AT INPUT X FREQ TO COMPARE WITH SCALED X-TRACE C
C C IF X-TRACE NOT SCALED, INSERT 3 BLANK CARDS IN DATA DECK, SO C
C C THAT THE FX AND H*X ARE ALL SET TO ZERO. C
C C CCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCCC C
C C
ISN 0007 SIN(X) = DSIN(X)
ISN 0008 COS(X) = DCOS(X)
ISN 0009 ATAN(X) = DATAN(X)
ISN 0010 -DSRT(X) = DSQRT(X)
ISN 0011 EXP(X) = DEXP(X)
ISN 0012 METHOD=1
ISN 0013 METHOD=2
C METHOD=1=LINEAR IN LOG N, METHOD=2=PARABOLIC IN LOG N
ISN 0014 SS(1) = 0.98940094
ISN 0015 SS(2) = 0.94457502
ISN 0016 SS(3) = 0.86563120
ISN 0017 SS(4) = 0.75540441
ISN 0018 SS(5) = 0.61787624
ISN 0019 SS(6) = 0.45801673
ISN 0020 SS(7) = 0.29160355
ISN 0021 SS(8) = 0.09501251
ISN 0022 SS(9) = -SS(8)
ISN 0023 SS(10) = -SS(7)
ISN 0024 SS(11) = -SS(6)
ISN 0025 SS(12) = -SS(5)
ISN 0026 SS(13) = -SS(4)
ISN 0027 SS(14) = -SS(3)
ISN 0028 SS(15) = -SS(2)
ISN 0029 SS(16) = -SS(1)
ISN 0030 SS(17) = 0.77459667
ISN 0031 SS(18) = 0.00000000
ISN 0032 SS(19) = -SS(17)

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BOTTOMSIDE

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ISN 0033      W(1) = 0.02715246
ISN 0034      W(2) = 0.06225352
ISN 0035      W(3) = 0.09515891
ISN 0036      W(4) = 0.12462897
ISN 0037      W(5) = 0.14959599
ISN 0038      W(6) = 0.16915652
ISN 0039      W(7) = 0.18260342
ISN 0040      W(8) = 0.18945061
ISN 0041      W(9) = W(8)
ISN 0042      W(10) = W(7)
ISN 0043      W(11) = W(6)
ISN 0044      W(12) = W(5)
ISN 0045      W(13) = W(4)
ISN 0046      W(14) = W(3)
ISN 0047      W(15) = W(2)
ISN 0048      W(16) = W(1)
ISN 0049      W(17) = 0.55555556
ISN 0050      W(18) = 0.88888889
ISN 0051      W(16) = W(17)
ISN 0052      AA(1)=0.0
ISN 0053      BB(1)=0.0
ISN 0054      BB(2)=0.0
ISN 0055      LL = 0
ISN 0056      WRITE (6,6003)
ISN 0057      6003 FORMAT (1 LAT,5X,'LONG',6X,'HT',5X,'DATE',9X,'EN',12X,'RE',12X,
1'BV',12X,'BT')
ISN 0058      DLAT = -60.0
ISN 0059      DLONG = -180.0
ISN 0060      ALT = 100.0
ISN 0061      DATE = 1960.0
ISN 0062      CALL FFIELD G(-60.0,-180.0,100.0,1960.0,20,L0,BN,RE,EV,BT)
ISN 0063      WRITE (6,6004) DLAT,DLONG,ALT,DATE,EN,RE,EV,BT
ISN 0064      6004 FORMAT (1,F7.2,2X,F7.2,2X,F6.1,2X,F6.1,2X,F12.4,2X,F12.4,2X,F12.4,
14.2X,F12.4)
ISN 0065      WRITE(6,802)
ISN 0066      802 FORMAT(1H1,37HREFERENCE DENSITIES FOR INTERPOLATION)
ISN 0067      WRITE(6,801)(DENRFF(K),K=1,84)
ISN 0068      801 FORMAT(2X,BE14.5)
ISN 0069      READ (5,6005) KZN,HTN,GN,GIN,KZD,GD,LD,DELTA
ISN 0070      6005 FORMAT(110.3F10.4/110.3F10.4)
C
C
C C CARDS FOR STANDARD RUN: REMAIN IN DECK AT ALL TIMES. KZN,HTN C
C C GN,GIN: A STARTS,INITIAL HT,STARTING FREQ. FREQ INCREMENT AT C
C C NIGHT; USUALLY=4,150.0,0.1,0.1. KZD,GD,GID: # STARTS,STARTING C
C C FREQ,FREQ INCREMENT FOR DAY, INITIAL HT=90 KM; USUALLY=3,16,1.6 C
C C DELTA=INCREMENT IN VALLEY DEPTH FOR STANDARD CASES, DAY/NIGHT C
C C IS DETERMINED BY HTREE (SEE BELOW). C
C C C
ISN 0071      READ (5,6001,END = 6000) TITLE
ISN 0072      6001 FORMAT (20A4)
ISN 0073      100 READ (5,101,END=6000) N,IYR,MD,MD,111,1DY,NV,LVA
ISN 0074      101 FORMAT (8I10)
C
C
C C FIRST (NV+1) LAMINATIONS ARE LINEAR IN LOG(N) TO SIMULATE C
C C VALLEY. JUMP OCCURS BETWEEN (NV-1) AND (NV) POINTS. LV = # C
C C OF VALLEY CORRECTIONS FOR WHICH CALCULATIONS ARE TO BE DONE. C

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C      C
ISN 0075      LV = 1 + LVA
ISN 0076      KW = NV+2
ISN 0077      DATE=FLOAT(IYR)+FLOAT(IDY)/365.0+1900.0
ISN 0078      METHOD = METHOD
ISN 0079      READ (5,102) HT, DIP, FHS, DLAT, DLONG,XDATA,RUN,VAL,START
ISN 0080      102 FORMAT (6F10.4,F4.1,2F8.4)
ISN 0081      HTREF=HT
C      C
C      HTREF=REFERENCE HT. IF HTREF < 120 KM, DAYTIME DATA IS ASSUMED IN
C      BOTH STANDARD AND SPECIAL RUNS. OTHERWISE, NIGHT DATA IS ASSUMED.
C      XDATA=-1.0 IF X TRACE UNSCALABLE. SET TO 0.0 OR LEAVE BLANK IF OK.
C      IF UNSCALABLE, 3 BLANK CARDS MUST BE INSERTED IN DATA DECK.
C      PUN=0 FOR A NORMAL RUN (OR LEAVE BLANK). RUN=1 FOR A SPECIAL RUN.
C      FOR A SPECIAL RUN: VAL = FRACTION OF THE DENSITY AT EMAX WHICH
C      REPRESENTS THE MAXIMUM DENSITY IN THE VALLEY; START = FRACTION
C      OF THE FREQUENCY AT EMAX WHICH REPRESENTS THE STARTING FREQUENCY.
C      C
ISN 0082      MP=10
ISN 0083      READ (5,103) (HF(I),F(I),I=1,N)
ISN 0084      103 FORMAT (8F10.4)
ISN 0085      NN = N - NV + 1
ISN 0086      READ (5,103) (HPXD(J),FXD(J), J = 1,MP)
ISN 0087      DO 3 M=1,N
ISN 0088      HPAP(M) = HF(M)
ISN 0089      HPA(M) = HP(M)
ISN 0090      3 CONTINUE
ISN 0091      KZ=KZD
ISN 0092      G=GD
ISN 0093      GI=GID
ISN 0094      IF (HT.LT. 120.0) GO TO 7000
ISN 0095      HT=HTN
ISN 0096      KZ=KZN
ISN 0097      G=GN
ISN 0098      GI=GIN
ISN 0100      7000 CONTINUE
ISN 0101      DO 4 M = 1,N
ISN 0102      HP(M) = -HPAP(M) + HT
ISN 0103      4 CONTINUE
C      C
C      LOOP ON VALLEY DEPTH.
ISN 0104      DO 2826 KV=1,LV
ISN 0105      FV=DELF*FLOAT(KV)-DELF
ISN 0106      IF (RUN.LE. 0.0) GO TO 7001
ISN 0107      FV=F(NV-1)*(1.0-SQRT(VAL))
ISN 0108      KZ=1
ISN 0110      G=F(NV-1)*START
C      C
C      LOOP ON STARTING FREQUENCY.
ISN 0111      7001 DO 2826 KF=1,KZ
ISN 0112      F(1)=G+GI*FLOAT(KF-1)
ISN 0113      WRITE (6,6002) TITLE
ISN 0114      6002 FORMAT (1H1,5X,20A4/1H ,5X,20A4)
ISN 0115      IF (METHOD-1)500,500,501
ISN 0116      500 WRITE(6,502)
ISN 0117      502 FORMAT(1H0,29HINVERSE CUBE,LINEAR IN LOG(N))
ISN 0118      GO TO 503
ISN 0119      501 WRITE(6,504)

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ISN 0120 504 FORMAT(1H0,32HINVERSE CUBE,PARABOLIC IN LOG(N))
ISN 0121 503 WRITE (6,303)
ISN 0122 603 FORMAT(1H0,10HINPUT DATA)
ISN 0123 WRITE (6,104) IYR,MO,MD,ITI,IDY
ISN 0124 104 FORMAT (1H0,8HYEAR 1912,3X,5HMONTH14,3X,3HDAY14,3X,19HLOCAL STAND
1ARD TIME,17,3X,7HDAY NO,14)
ISN 0125 WRITE (6,3010) FV
ISN 0126 3010 FORMAT (1, DEPTH OF E-VALLEY = ',F7.2,' MHZ,')
ISN 0127 WRITE(6,2005)
ISN 0128 2005 FORMAT(1H ,7HO TRACE)
ISN 0129 WRITE(6,106)
ISN 0130 106 FORMAT(1H ,5(3X,1HF,6X,2HMP,2X))
ISN 0131 WRITE (3,107)(F(1),HPA(1),I=1,N)
ISN 0132 107 FORMAT(5(1X,F6.3,1X,F6.1))
ISN 0133 CALL F1FLG(DLAT,DLENG,HT,DATE,20,LQ,PN,BE,BV,BT)
ISN 0134 FT = BT
ISN 0135 FV = BV
ISN 0136 HH = SQRT(FT**2-FV**2)
ISN 0137 BVH = BV/HH
ISN 0138 DIP = ATAN(BVH)/57.29578
ISN 0139 FH(1)=BT*2,5000E-05
ISN 0140 FHS = FH(1)
ISN 0141 WRITE(6,2007),HT
ISN 0142 2007 FORMAT (1H0,'DIP AND FHS AT ',F5.0,' KM COMPUTED FROM FIELD G,')
ISN 0143 WRITE (6,105) DIP,FHS,DLAT,DLENG
ISN 0144 105 FORMAT (1H ,5'DIP=',F10.4,3X,'FHS=',F10.4,3X,'DLAT=',F10.4,3X,'DLENG
16=',F10.4)
ISN 0145 WRITE(6,108)
ISN 0146 108 FORMAT (1H0,6X,1HF,16X,4HELC,14X,6HPE1GHT,4X,9HITERATION,8X,2HFH,
11X,12HPREVIOUS HGT,9X,5HSLCPE)
ISN 0147 DIP = 50RT(DIP,DIP)
ISN 0148 A=(90,0-DIP)/57.29577
ISN 0149 CPH=COS(A)
ISN 0150 HGT = HT
ISN 0151 FH(1) = FHS
ISN 0152 TH(1) = HT
ISN 0153 10 DEN(1)=F(1)*F(1)*12400.00
ISN 0154 ELCC = DEN(1)
ISN 0155 FA = F(1)
ISN 0156 NL = N
ISN 0157 WRITE(6,173)FA,ELCC,HT
ISN 0158 173 FORMAT(1H0,F12.4,6X,F12.4,6X,F12.4)
ISN 0159 FH(1) = FHS
ISN 0160 DO 25 I=2,N
ISN 0161 15 DP = 0.0
ISN 0162 IQ = 0
ISN 0163 IF(I-NL)5,8,25
ISN 0164 8 TEST = F(I-1) + 0.001
ISN 0165 FREQ = F(I)
ISN 0166 IF (FREQ-15.0) 4000,29,29
ISN 0167 4000 IF (FREQ-TEST) 29,12,12
ISN 0168 29 NL = NL-1
ISN 0169 FA = F(I)
C BAD DATA POINTS ARE REJECTED IN DD 33
ISN 0170 DD 33 LEI,NL
ISN 0171 HP(L) = HP(L+1)

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ISN 0172      HPA(L)=HPA(L+1)
ISN 0173      33 F(L) = F(L+1)
ISN 0174      WRITE(6,11)FA
ISN 0175      11 FORMAT (1H 'DATA FOR F=,F6.3,' HAS BEEN REJECTED - VALLEY SHOULD
              1 BE CHECKED.')
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ISN 0176      GO TO 15
ISN 0177      12 CONTINUE
ISN 0178      500 FH(I)=FH(I-1)
ISN 0179      901 GIRC = FH(I)
ISN 0180      TH(I) =TH(I-1)
ISN 0181      HGT=TH(I-1)
ISN 0182      FA = F(I)
ISN 0183      FAFA = FA*FA
ISN 0184      M = 2
```

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C      YR=Y AT REFLECTION POINT
ISN 0185      14 YR=0.0
ISN 0186      HGTA = TH(I)
ISN 0187      GYRC = FH(I)
ISN 0188      DD 24 J=M.1
ISN 0189      IF (J-KV) 4001,4002,4001
ISN 0190      4002 F1F1 = (F(J-1)-FV)*(F(J-1)-FV)
ISN 0191      GO TO 4003
ISN 0192      4001 F1F1 = F(J-1)*F(J-1)
ISN 0193      4003 F2F2 = F(J)*F(J)
ISN 0194      Y1 = FH(J-1)/FA
ISN 0195      Y2 = FH(J)/FA
ISN 0196      X1 = F1F1/FAFA
ISN 0197      X2 = F2F2/FAFA
```

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C      CHANGE FROM VARIABLE X TO VARIABLE T
ISN 0198      T1 = SQRT (1.0-(X1/(1.0-YR)))
ISN 0199      S1 = 0.0
ISN 0200      S2=0.0
```

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C      B0 AND C0 ARE USED IN FORMULA TO CHANGE Y WITHIN LAMINATION
ISN 0201      B0 = DLOG(Y2/Y1)/3.0
ISN 0202      V0=DLOG(X2/X1)
ISN 0203      IF (J-1) 19,18,18
ISN 0204      18 T2 = 0.0
ISN 0205      IF(METHOD-1)151,151,506
ISN 0206      506 IF (I-KV) 151,151,155
ISN 0207      155 IF(IQ-1)151,152,152
ISN 0208      151 ALIM = 1.0
ISN 0209      RA = 1.0
ISN 0210      RB = 0.0
ISN 0211      GO TO 156
ISN 0212      152 AA(I) = AA1
ISN 0213      153 BB(I) = (TH(I)-TH(I-1)-AA(I)*V)/(V*V)
ISN 0214      AA(I+1)=AA(I)+(2.0)*BB(I)*V
ISN 0215      ALIM = AA(I+1)/AA(I)
ISN 0216      GO TO 154
ISN 0217      19 T2 = SQRT (1.0-(X2/(1.0-YR)))
ISN 0218      IF(METHOD-1)151,151,508
ISN 0219      508 ALIM = 1.0
ISN 0220      154 RB = BB(J)/AA(J)
ISN 0221      RA = 1.0+RB*V
ISN 0222      156 C0 = (EXP(R0)-1.0)/(V*RA)
C      GAUSSIAN INTEGRATION
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ISN 0223      20 DO 605 K=1,16
ISN 0224        T = 0.5*((T1-T2)*SS(K)+T1+T2)
ISN 0225        X=(1.0-T*T)* (1.0-YR)
ISN 0226        A = DLGG(X2/X)
ISN 0227        Y = Y2/((1.0+C0*A*(1.0+RB*(2.0*V-A)))*3)
ISN 0228      602 VL = Y * CPH
ISN 0229        Y12 = Y*Y*(1.0-CPH*CPH)
ISN 0230        IF (CPH-0.0000) 603,604,604
ISN 0231      604 R = Y12/(2.0*VL)
ISN 0232        R = R/(1.0-X)
ISN 0233        PSI = ATAN(R)
ISN 0234        A = (1.0+SIN(PSI))*SORT(1.0+R*R)
ISN 0235        SD=1.0*VL/A
ISN 0236        GO TO 609
ISN 0237      608 PSI = 1.57079
ISN 0238        UX=1/(X*SORT(1.0-X))
ISN 0239        GO TO 603
ISN 0240      609 R=X/SD
ISN 0241      IF(1.000000 -R)29,29,612
C      REJECTS HAD DATA CARDS
ISN 0242      612 U = SORT (1.0-R)
ISN 0243        C=(1.0-SD)/(2.0*SD)
ISN 0244        D=1.0-((1.0+X)*SIN(PSI))/(1.0-X)
ISN 0245        UP = (1.0 + B*C*D)/U
ISN 0246        UX =(UP * T)/X
ISN 0247      603 S1 = S1+UX*W(K)
ISN 0248        UX2=UX*DLGG(X/X1)
ISN 0249        S2=S2+UX2*W(K)
ISN 0250      605 CONTINUE
ISN 0251        ASUM=S1*(T1-T2)
ISN 0252        BSUM=S2*(T1-T2)*2.0
ISN 0253        IF (J-1) 23,25,25
ISN 0254      23 DP=DP-AA(J)*ASUM-BB(J)*BSUM
ISN 0255      24 CONTINUE
C      FIRST LAMINATION COMPUTED WITH LINEAR METHOD
ISN 0256      25 IF (I-KW) 60,60,61
ISN 0257      60 METHOD = 1
ISN 0258        GO TO 70
ISN 0259      61 METHOD =METCD
ISN 0260        IF (METHOD-1)70,70,510
C      FIRST ESTIMATE OF HGT COMPUTED WITH LINEAR METHOD
ISN 0261      510 IF (I-1)70,71,71
ISN 0262      70 AB=(DP-HP(I))/ASUM
ISN 0263        TH(I)=TF(I-1)+AB*DLGG(X2/X1)
ISN 0264        AA(I)=AB
ISN 0265        IF (I-KW) 75,75,76
ISN 0266      75 AAT = AB
ISN 0267      76 BG(I)=0.0
ISN 0268        HGT=TH(I)
ISN 0269        IF (METHOD-1)62,62,67
ISN 0270      71 BR11 =(DP-AA(I)*ASUM-HP(I))/BSUM
ISN 0271        V=DLGG(X2/X1)
ISN 0272        TH(I)=TH(I-1)+AA(I)*V+BR11 *V*V
ISN 0273        BR(I) = BR11
ISN 0274      62 HGT =TH(I)
C      CONVERGENCE TEST TO INSURE THAT SUCCESSIVE HT. ARE WITHIN 0.01 KM

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ISN 0275      A = HGT-HGTA
ISN 0276      A = 0.0001- A*A
ISN 0277      IF(A) 27,30,30
ISN 0278      27  IO = IO+1
ISN 0279      M=1
C             ITERATE ONLY FOR LAST LAMINATION (M=1),10 ITERATIONS MAX. NO.
ISN 0280      IF(10-5)66,66,30
ISN 0281      66  FH(I) = FHS*{((6371.0*HT)/(6371.0+HG))**3}
ISN 0282      DEN(I)=F(I)*F(I)*12400.00
ISN 0283      ELCC = DEN(I)
ISN 0284      A = DEN(I) - DEN(I-1)*1.001
C             IF DENSITY DOES NOT INCREASE BY AT LEAST 0.1 PER CENT, REJECT P.T
ISN 0285      IF(A)29,14,14
ISN 0286      30  V = CLCG(X2/X1)
ISN 0287      AAI = AAI+(2.0)*BP(I)*V
ISN 0288      WRITE(6,172)FA,ELCC,HGT,IO,GYRD,HGTA,AAI
ISN 0289      172  FORMAT(1H ,F12.5,6X,F12.4,6X,F12.4,6X,I2,6X,F12.6,6X,F12.4,6X,
1F12.4)
ISN 0290      26  CONTINUE
ISN 0291      CALL NHMAX(IFLAG)
ISN 0292      IF (IFLAG .EQ. 0) GO TO 176
ISN 0293      WRITE(6,174)
ISN 0294      174  FORMAT(1H0,'CALCULATION OF HMAX AND NMAX ASSUMING PARABOLIC PEAK O
1F THE FORM: '1H ,5X,'N = NMAX(1-(H-HMAX))(H-HMAX))/CONSTANT ')
ISN 0295      WRITE(6,175)HMAX,DMAX,RATIO
ISN 0296      175  FORMAT(1H0,'HMAX = ',F6.1,' KM AND NMAX = ',D9.3,' EL/CC.'/1H ,
1F
1THE RATIO OF THE LAST TWO SLOPES IS:',F6.3)
ISN 0297      WRITE(6,179)
ISN 0298      179  FORMAT(1H0,2X,4('ALT,',3X,'DENSITY',4X))
ISN 0299      KB=N+1
ISN 0300      XC=N+10
ISN 0301      WRITE(6,700){TH(K),DEN(K),K=KB,KC}
ISN 0302      GO TO 180
ISN 0303      176  WRITE(6,177)RATIO
ISN 0304      177  FORMAT(1H0,'RATIO OF LAST TWO SLOPES IS TOO CLOSE TO UNITY FOR REL
1TABLE EXTRAPOLATION. RATIO = ',F6.3)
ISN 0305      180  WRITE (6,6302 ) TITLE
ISN 0306      C      CALCULATION OF EXT. RAY VIRTUAL HEIGHTS
ISN 0307      FX(I) = (FH(I)+SQRT(4.0*F(I)*F(I)+FH(I)*FH(I)))/2.0
ISN 0308      HPX(I) = HT
ISN 0309      DO 1024 I=2,NL
ISN 0310      DP = 0.0
ISN 0311      FX(I)=(FH(I)+SQRT(4.0*F(I)*F(I)+FH(I)*FH(I)))/2.0
ISN 0312      FA = FX(I)
ISN 0313      FAFA = FA*FA
ISN 0314      YR = FH(I)/FA
ISN 0315      DO 1024 J=2,I
ISN 0316      IF (J-NV) 5001,5002,5001
ISN 0317      5002 F1F1 = (F(J-1)-FV)*(F(J-1)-FV)
ISN 0318      GO TO 5003
ISN 0319      5001 F1F1 = F(J-1)*F(J-1)
ISN 0320      5003 F2F2 = F(J)*F(J)
ISN 0321      Y1 = FH(J-1)/FA
ISN 0322      Y2 = FH(J)/FA
ISN 0323      X1 = F1F1/FAFA
ISN 0324      X2 = F2F2/FAFA

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C      CHANGE FROM VARIABLE X TO VARIABLE Y
      T1 = SQRT (1.0-(X1/(1.0-YR)))
      S1 = 0.0
      S2 = 0.0
C      BQ AND CQ ARE USED IN FORMULA TO CHANGE Y WITHIN LAMINATION
      BQ = DLOG(Y2/Y1)/3.0
      V = DLOG(X2/X1)
      IF (J-1) 1019,1018,1018
1018  T2 = 0.0
      GO TO 1154
1019  T2 = SQRT (1.0-(X2/(1.0-YR)))
1154  RB = BB(J)/AA(J)
      RA = 1.0+RB*V
1156  CQ = (EXP(BQ)-1.0)/(V*RA)
C      GAUSSIAN INTEGRATION
1020  DO 1605 K=1,7,19
      T = 0.5*((T1-T2)*SS(K)+T1+T2)
      X=(1.0-T*T)*(1.0-YR)
      A = DLOG(X2/X)
      Y = Y2/((1.0+CQ*AA*(1.0+RB*(2.0*V-A)))*3)
1602  YL = Y *CPH
      YT2 = Y*Y*(1.0-CPH*CPH)
      IF(CPH-0.0009) 1608,1604,1604
1604  R = YT2/(2.0*YL)
      R = R/(1.0-X)
      PSI = ATAN(R)
      A = (1.0+SIN(PSI))*SQRT(1.0+R*R)
      SX = 1.0-A*YL
      GO TO 1609
1608  PSI = 1.57079
      SX = 1.0 - (Y*Y)/(1.0-X)
1609  B = X/SX
      HO = 1.0 -B
      IF(BQ)1029,1029,1612
C      REJECTS HAD DATA CARDS
1612  U = SQRT(BQ)
      C = (1.0-SX)/(2.0*SX)
      D = 1.0 + ((1.0+X)*SIN(PSI))/(1.0-X)
      UP = (1.0 + B+C*D)/U
      UX = (UP * T)/X
1603  S1 = S1+UX*B(K)
      UX2 = UX*DLOG(X/X1)
      S2 = S2+UX2*B(K)
1605  CONTINUE
      SA=S1*(T1-T2)*0.5
      ASUM=(2.0-YR-YR)*SA
      SB=S2*(T1-T2)*0.5
      BSUM=1.0*(1.0-YR)*SB
1023  DP = DP-AA(J)*ASUM-BB(J)*BSUM
1024  CONTINUE
      GO TO 1028
1029  DP = 0.0
1028  HPX(I) = -DP + HT
      WRITE (6,2000) DP
2000  FORMAT(1H0,23HCOMPUTED EXTRAORD TRACE,SX,4XDIP=F10.4)
      WRITE (6,106)

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ISN 0377      WRITE (6,107) (FX(I),HPX(I),I=1,NL)
ISN 0378      LK = 1
ISN 0379      NW = NV
ISN 0380      IF ( NV.GE. 1 ) GO TO 2345
C             IF ALL POINTS ARE ABOVE VALLEY ( E.G. AT NIGHT), USE ALL POINTS
C             EXCEPT THE FIRST, WHICH IS SET BY THE PROGRAM, FOR THIS INTERPOLATION.
NW=2
ISN 0382      2345 DO 817 LL = NW,N
ISN 0383          HPP(LK) = HPX(LL)
ISN 0384          FZ(LK) = FX(LL)
ISN 0385          LK = LK + 1
ISN 0386      817 CONTINUE
ISN 0387          NJ = LK-1
ISN 0388          WRITE (6,668)
ISN 0389          668 FORMAT(1H0,66H EXTRAORDINARY TRACE COMPUTED FROM ORDINARY TRACE AN
ISN 0390              1D INPUT TO TAB)
ISN 0391              WRITE (6,106)
ISN 0392              WRITE (6,107) ( FZ(I),HPP(I), I = 1,NJ )
C             ROUTINE TO COMPARE COMPUTED X-TRACE WITH SELECTED SCALED EXT POINTS
ISN 0393          LIM1 = -4
ISN 0394          STDV1=0.0
ISN 0395          STD1=0.0
ISN 0396          DO 291 I=1,2
ISN 0397              LIM1 = LIM1+5
ISN 0398              LIM2 = LIM1+4
ISN 0399              STD = 0.0
ISN 0400              STDDV = 0.0
ISN 0401              DO 290 JK=LIM1,LIM2
ISN 0402                  FXX = FXD(JK)
ISN 0403                  HPXX(JK) = TAB(FZ,HPP,NJ,3,FXX)
ISN 0404                  DIFF(JK) = HPXX(JK) - HPXD(JK)
ISN 0405                  IF (FXX.GE. FZ(1)) GO TO 293
ISN 0406                  IF (HTREF.GT. 120.0) GO TO 294
ISN 0407                  DIFF(JK)=0.0
ISN 0408                  GO TO 294
ISN 0409      293 IF (FXX.LE. FZ(NJ)) GO TO 294
ISN 0410          DIFF(JK)=0.0
ISN 0411      294 STDDV=STDDV+DIFF(JK)**2
ISN 0412          STD = STD+DIFF(JK)
ISN 0413      250 CONTINUE
ISN 0414          STDV(1)=SQRT(STDDV/5.0)
ISN 0415          STDD(1)=STD/5.0
ISN 0416          WRITE (6,670) I
ISN 0417      670 FORMAT (1H0,55H INPUT EXTRAORDINARY TRACE SCALED FROM IONOGRAM - P
ISN 0418          1ART,12)
ISN 0419          WRITE (6,675)
ISN 0420      675 FORMAT (' ', 1X, 5('FXD',4X,'HPXD',3Y))
ISN 0421          WRITE (6,107) ( FXD(J), HPXD(J), J=LIM1,LIM2)
ISN 0422          WRITE (6,666) I
ISN 0423      666 FORMAT (1H0,70H INTERPOLATED EXTRAORDINARY TRACE COMPUTED FROM ORD
ISN 0424          INARY TRACE - PART,12)
ISN 0425          WRITE (6,610)
ISN 0426      610 FORMAT (' ', 1X, 5('FXD',4X,'HPXX',3X))
ISN 0427          WRITE (6,107) (FXD(J),HPXX(J),J=LIM1,LIM2)
ISN 0428          IF (XDATA.LT. 0.0) WRITE (6,49)
ISN 0429      49 FORMAT (1H0,'THE X TRACE WAS UNSCALABLE FOR THIS IONOGRAM.'/1H,
ISN 0430

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2111 THEREFORE COULD NOT BE COMPARED TO THE COMPUTED X TRACE.**)
ISN 0432      WRITE (6,657) STDV(I),STDD(I)
ISN 0433      667  FORMAT (10I, 1X, 'DIFFERENCE BETWEEN INTERPOLATED AND SCALED X TRA
1CF, 5X, 'STANDARD DEVIATION = ',F9.4,5X, 'AVERAGE = ',F9.4)
ISN 0434      WRITE (6,665)
ISN 0435      665  FORMAT (1I, 1X, 5('FXD', 4X, 'DIFF', 3X))
ISN 0436      WRITE (6,107) (FXD(J),DIFF(J),J=LIM1,LIM2)
ISN 0437      STDV=STDV+STDDV
ISN 0438      STD1=STDV+STDD(I)
ISN 0439      251  CONTINUE
ISN 0440      STDV=SQRT(STDV/10.0)
ISN 0441      STD1=STD/2.0
ISN 0442      WRITE (6,292) STDV,STD1
ISN 0443      292  FORMAT (1H0, 'TOTAL STANDARD DEVIATION ',F9.4,5X, 'TOTAL AVERAGE ',F
19.4)
ISN 0444      8000 CONTINUE
C      INTERPOLATION ROUTINE
ISN 0445      N = NL
ISN 0446      DO 280 I=1,N
ISN 0447      280  DENL(I) = DLOG(DEN(I))
ISN 0448      N=N-1
ISN 0449      M=1
ISN 0450      K=1
ISN 0451      DO 816 L=1,N
ISN 0452      K=K-1
ISN 0453      D2A = DEN(L)
ISN 0454      D2B = DEN(L+1)
ISN 0455      Z2A = 1H(L)
ISN 0456      Z2B = 1H(L+1)
ISN 0457      810  K=K+1
ISN 0458      D1 = DENREF(K)
ISN 0459      IF (D1-D2A) 810,812,813
ISN 0460      812  DENINT(M) = D1
ISN 0461      ZINT(M) = Z2A
ISN 0462      M=M+1
ISN 0463      GO TO 810
ISN 0464      813  IF (D1-D2B) 814,815,816
ISN 0465      814  DENINT(M) = D1
ISN 0466      819  V= DLOG(D1/D2A)
ISN 0467      ZINT(M)=Z2A+AA(L+1)*V+BB(L+1)*V*V
ISN 0468      M=M+1
ISN 0469      GO TO 810
ISN 0470      815  DENINT(M)=D1
ISN 0471      ZINT(M)=Z2B
ISN 0472      M=M+1
ISN 0473      816  CONTINUE
ISN 0474      N = N+1
ISN 0475      ZINT(M)=TH(N)
ISN 0476      DENINT(M)=DEN(N)
ISN 0477      HTR1=DFLOAT(1FIX(SNGL(TH(NV)+10.0))/10.0)*10.0
ISN 0478      IF (HTRF .GE. 120.0) HTR1=DFLOAT(1FIX(SNGL(ZINT(1)+10.0))/10.0)*10.0
ISN 0479      IF (HTR1 .LT. 140.0) HTR1=140.0
ISN 0480      HTR2=TH(N)
ISN 0481      IF (HTR2 .GT. 500.0) HTR2=500.0
ISN 0482      MM=1FIX(SNGL(HTR2-HTR1)/10.0)+1
ISN 0483      DO 820 L=1,MM
ISN 0484

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15N 0467      HINT(L)=HTR1+DFLOAT(L-1)*10.0
15N 0468      E20 DINT(L)=TAB(ZINT,DENINT,M*3,HINT(L))
15N 0469      MM=MM+1
15N 0470      HINT(MM)=TH(N)
15N 0471      DINT(MM)=DEN(N)
15N 0492      WRITE (6,5002) TITLE
15N 0497      IF (METHOD-1) 50,50,51
15N 0494      50 WRITE (6,502)
15N 0495      GO TO 52
15N 0496      51 WRITE (6,504)
15N 0497      52 WRITE (6,503)
15N 0498      WRITE (6,104) 1YR,MC,MC,ITI,1DY
15N 0499      WRITE (6,2007) HT
15N 0500      WRITE (6,105) DIP,FHS,OLAT,CLONG
15N 0501      WRITE (6,53) DEN(1),HT
15N 0502      53 FORMAT (1H0,'ANALYSIS ASSUMES THAT THE ELECTRON DENSITY IS:',F7.1,
1      '1' EL/CC AT ',F5.0,' KM,'/1H ',5X,'0.0 EL/CC BELOW THIS ALTITUDE,AND
2      '2 INCREASING '/1H ',5X,'EXPONENTIALLY UP TO THE FIRST DATA POINT SCAL
3      '3ED FROM THE IONOGRAM.')
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15N 0503      IF (HT .NE. 90.) GO TO 54
15N 0505      IF (FV-LT, 0.001) GO TO 57
15N 0507      DMIN=(F,NV-1)-FV)
15N 0508      DMIN=DMIN*DMIN*12400.
15N 0509      VAL=DMIN/DEN(NV-1)
15N 0510      WRITE (6,55) TH(NV-1),DEN(NV-1),TH(NV),DEN(NV),DMIN,VAL
15N 0511      55 FORMAT(1H0,'CALCULATIONS ASSUME A VALLEY BETWEEN ',F5.1,' KM (',F7
1      '1.0,' EL/CC) AND ',F6.1,' KM'/1H ',5X,'( ',F7.0,' EL/CC). THE MINIMUM
2      '2 DENSITY IN THE VALLEY IS ',F7.0,' EL/CC,'/1H ',5X,'1.E. ',F4.2,
3      '3' * (DENSITY AT EMAX).')
```

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15N 0512      GO TO 54
15N 0513      57 WRITE (6,56) TH(NV-1),DEN(NV-1),TH(NV),DEN(NV)
15N 0514      58 FORMAT (1H0,'CALCULATIONS ASSUME NO VALLEY BETWEEN ',F5.1,' KM (',
1      '1F7.0,' EL/CC) AND ',F5.1,' KM'/1H ',5X,'( ',F7.0,' EL/CC).')
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15N 0515      54 IF (XDATA .GE. 0.0) GO TO 59
15N 0517      WRITE (6,49)
15N 0518      GO TO 48
15N 0519      59 WRITE (6,56) STDVT,STDV
15N 0520      56 FORMAT (1H0,'STANDARD DEVIATION FOR DIFFERENCES BETWEEN SCALED X-T
1      '1RACE AND '/1H ',5X,'X-TRACE COMPUTED FROM O-TRACE = ',F7.2,' KM'/1H
2      '2, AVERAGE OF DIFFERENCES BETWEEN THESE TRACES = ',F7.2,' KM')
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15N 0521      48 WRITE (6,701)
15N 0522      WRITE (6,700) (ZINT(K),DENINT(K),K=1,M)
15N 0523      700 FORMAT(4(2X,F6.1,E10.3))
15N 0524      701 FORMAT (1H0,'ALTITUDES (KM) AND ELECTRON DENSITIES (EL/CC) AT SELE
1      '1CTED DENSITY',F7.1H ',5X,'(EXCEPT IN E-VALLEY)'/1H ',2X,4('ALT.',3X,'
1      '1 DENSITY',4X),
2      '2 WRITE (6,821)
3      '3 WRITE (6,700) (HINT(K),DINT(K),K=1,M)
4      '4 821 FORMAT (1H0,'ELECTRON DENSITIES AT SELECTED ALTITUDES ABOVE THE E-
5      '5 F VALLEY',F7.1H ',2X,4('ALT.',3X,' DENSITY',4X))
6      '6 IF (RATIO,GT,0.97)GO TO 181
7      '7 WRITE (6,174)
8      '8 WRITE (6,175)HMAX,DMAX,RATIO
9      '9 WRITE (6,179)
0      '0 WRITE (6,700) (TH(K),DEN(K),K=KB,KC)
1      '1 GO TO 282B
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ISN 0535 191 WRITE(6,177)RATIO
ISN 0536 2E28 CONTINUE
ISN 0537 GO TO 100
ISN 0538 KCCO STOP
ISN 0539 END


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IEF2851 MMLoad
IEF2851 VOL SER NOS= M2LCAD.
IEF2851 SYS1.DUMMY
IEF2851 VOL SER NOS= M2DRM1.
IEF2851 SYS1.DUMMY
IEF2851 VOL SER NOS= M2DRM1.
IEF2851 SYS1.FORTLIB
IEF2851 VOL SER NOS= M2DRM1.
IEF2851 SYS1.PL1LIB
IEF2851 VOL SER NOS= M2EYS4.
IEF2851 SYS1.GS-CLIB
IEF2851 VOL SER NOS= M2EYS2.
IEF2851 SYS1.EBP
IEF2851 VOL SER NOS= M2EYS2.
IEF2851 SYS1.COBLIB
IEF2851 VOL SER NOS= M2EYS2.
IEF2851 SYS71123.T092251.RV000.L5JEJ007.LGDMD PASSED
IEF2851 VOL SER NOS= M2SCR6.
IEF2851 SYS71123.T092251.SV000.L5JEJ007.R0001114 SYSCUT
IEF2851 VOL SER NOS= M2SCR6.
IEF2851 SYS71123.T092251.RV000.L5JEJ007.R0001116 DELETED
IEF2851 VOL SER NOS= M2SCR6.
IEF2851 SYS71123.T092251.RV000.L5JEJ007.CBJMCD DELETED
IEF2851 VOL SER NOS= M2SCR6.
IEF2851 SYS71123.T092251.RV000.L5JEJ007.S0001116 SYSIN
IEF2851 VOL SER NOS= M2SCR3.
IEF2851 SYS71123.T092251.RV000.L5JEJ007.S0001116 DELETED
IEF2851 VOL SER NOS= M2SCR3.
IEF3731 STEP /LINK / START 71123.1304
IEF3741 STEP /LINK / STOP 71123.1304 CPU 00MIN 00.65SEC MAIN 154K LGS OK
- STEP 02 -
IC IN SECS. DISK= 9.45, DRUM= 2.76, TAPE= .21 MINS=(CPU= .01, IC= .20)
STEP TIME = .00, CELL = .00, CTHR= .00
XXGO EXEC PGM=*, LINK, SYSLMCD, CCND=(5,LT), REGION=100K 00002000
XXF705F001 DD DDNAME=DATA5 00002100
XXF706F001 DD SYSOUT=A, DCB=( RECFM=VBA, LRECL=137, BLKSIZE=7265) 00002200
XXF707F001 DD DUMMY, DCB=( RECFM=FB, LRECL=80, BLKSIZE=3200) X0002300
XX* TO GET A DECK, ADD THE FOLLOWING CARD TO YOUR DECK X0002400
XX* //GO.F07F001 DD DDNAME=DECK, SYSCUT=B 00002500
XX* //GO.F07F001 DD DDNAME=DECK, SYSCUT=B 00002600
XXSYSPRINT DD SYSOUT=A, DCB=( RECFM=VBA, LRECL=137, BLKSIZE=7265)
//GO, DATA5 DD *
//
IEF2361 ALLOC. FOR L5JEJ007 GO
IEF2371 334 ALLOCATED TO PGM=*, DD
IEF2371 334 ALLOCATED TO F705F001
IEF2371 332 ALLOCATED TO F706F001
IEF2371 333 ALLOCATED TO SYSPRINT

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LAT	LONG	HT	DATE	RN	RE	BV	RT
-60.00	-180.00	100.0	1960.0	9829.9102	7857.0898	-60621.6289	61913.9961

REFERENCE DENSITIES FOR INTERPOLATION

0.100000 05	0.200000 05	0.300000 05	0.400000 05	0.500000 05	0.600000 05	0.700000 05	0.800000 05
0.900000 05	0.100000 06	0.110000 06	0.120000 06	0.130000 06	0.140000 06	0.150000 06	0.160000 06
0.170000 06	0.180000 06	0.190000 06	0.200000 06	0.210000 06	0.220000 06	0.230000 06	0.240000 06
0.250000 06	0.260000 06	0.270000 06	0.280000 06	0.290000 06	0.300000 06	0.320000 06	0.340000 06
0.360000 06	0.380000 06	0.400000 06	0.420000 06	0.440000 06	0.460000 06	0.480000 06	0.500000 06
0.520000 06	0.540000 06	0.560000 06	0.580000 06	0.600000 06	0.620000 06	0.640000 06	0.660000 06
0.680000 06	0.700000 06	0.720000 06	0.740000 06	0.760000 06	0.780000 06	0.800000 06	0.850000 06
0.900000 06	0.950000 06	0.100000 07	0.110000 07	0.120000 07	0.130000 07	0.140000 07	0.150000 07
0.160000 07	0.170000 07	0.180000 07	0.190000 07	0.200000 07	0.220000 07	0.240000 07	0.260000 07
0.280000 07	0.300000 07	0.320000 07	0.340000 07	0.360000 07	0.380000 07	0.400000 07	0.420000 07
0.440000 07	0.460000 07	0.480000 07	0.500000 07				