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Technical Memorandum 70-3
IONOSPHERIC ELECTRON DENSITY PROFILE MODEL
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by

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and

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1. Preface.

Recent investigation of the effects of ionospheric retardation and refraction on satellite tracking radars has generated a need for a means to predict the errors and correct for them. This paper describes a project undertaken by 8th Weather Wing to produce a realistic electron density profile based upon parameters which can be forecast reasonably accurately. The authors wish to acknowledge the help provided them in this project. Lt Colonel Hansrote provided the impetus for producing such a model. Capt Jack Wrobel solved our initial problems of scale height by providing "Wrobel's Equation." MSgt Birch and TSgtuster analyzed and evaluated the model against actual observations. Mrs. Green accomplished the manuscript typing. Thanks also to Lt Bo Eross for his system analysis suggestions.

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II. Introduction.

The development of a computer program for predicting electron density profiles was prompted by the realization that ionospheric retardation and refraction produced errors in range and azimuth of satellite tracking radars. These errors are of the same order of magnitude as those produced by tropospheric effects when the UHF radars are operating above a few degrees elevation. Since the effects are rather small, it was assumed that a simple model from 100 km to 1000 km would be sufficient. However, as development work began, other requirements for electron density profiles became apparent. A three-dimensional ionosphere for HF ray tracing, which requires considerably more accuracy in the lower ionosphere, was requested. In addition, total electron content for correcting for Faraday rotation in some navigational satellites requires a model extending higher than 1000 km.

The program described in this report has been used routinely for about eight months to predict electron density profiles for the FPS-85 radar at Eglin AFB, Fla. Results are encouraging enough to warrant publication. It should be considered an interim report, however, as improvements are sure to be required as its accuracy is evaluated for different purposes.
III. Development.

The ionospheric electron density profile model presented in this paper consists of the sum of three Chapman layers (E, F1, and F2). Each layer is of the form

\[ N_h = N_{\text{max}} \exp \left( a \left( 1 - \exp\left(-Z\right) \right) \right) \]

where \( Z = \frac{h-h_{\text{max}}}{h_s} \)

- \( N_h \) = electron density at height \( h \)
- \( N_{\text{max}} \) = electron density at the peak of the Chapman layer \( h_{\text{max}} \)
- \( h_s \) = scale height at the peak (except for the topside of the F2 region)

The value of the constant, \( a \), depends upon whether electrons are lost by attachment or by recombination. While neither process is unique in any layer, \( a \) is assumed to be 0.5 for the E-layer and 1.0 for the F1 and F2 layers.

Electron densities in the topside ionosphere are controlled by complex motions rather than a production-loss balance and cannot be successfully described strictly by a Chapman layer. An effort was made to keep from over-complicating the model and still obtain the best topside profile. After some experimentation a fit was obtained by simply using the Chapman equation for the topside ionosphere, but computing the electron densities by using a variable scale height throughout the region.

The scale height profile is calculated from the equation

\[ h_s = \frac{\log h}{2.186 \times 10^{-2} - 203.447} \]

This equation describes the scale height of a simple standard atmosphere and was derived by Capt J. Wrobel (private communication).

Critical frequencies for the E and F1 regions are determined from regression equations [1], [2],

\[ f_{0E} = 0.9(180 + 1.44R) \cos x^{0.25} \]

\[ f_{0F1} = 1.26f_{0E} + 0.5 \]

where \( R \) = the twelve-month running mean sunspot number
- \( x \) = the solar zenith angle

When \( x \) exceeds 90°, \( f_{0E} \) is set to 0.7 MHz. When \( x \) exceeds 135°, \( f_{0E} \) is set to 0.3 MHz.

The F2 region critical frequency may be predicted from the ITS (ESSA) coefficients by predicting a sunspot number (R) [1]. It may also be predicted manually on a short-term basis by the Air Force Aerospace Environmental Support Center. For post analysis purposes, an observed value may be used.

The height of the peak of the E region is assumed to be 120 km. After some experimentation, the F1 peak was placed halfway between the E and F2 peaks.

The height of the F2 peak is calculated by using Shimazaki's equation [3]:

\[ h_{\text{max}} = \frac{1890}{M} - 176 \]

where the \( M(3000) \) factor, \( M \), may be predicted in a manner similar to the prediction of \( f_{0F2} \), or observed. Computations of \( h_{\text{max}} \) using \( M(3000) \) were found to be accurate within 20 km at mid latitudes. If a more accurate measure of \( h_{\text{max}} \) is available,
such as $h_p F_2$, an artificial $M(3000)$ may be calculated from the Shimazaki equation and used as an input into the computer program.

IV. Description of the Computer Program.

A copy of the computer program used to compute an electron density profile is listed in Appendix A. The program is written in IBM 7090 FORTRAN IV. There are three input options (all of which are concerned with the method of obtaining $f_0 F_2$ and $M(3000)$). Two output options are available, depending upon the representation of the profile required.

The program computes electron densities independently for each of three regions ($E$, $F_1$, and $F_2$). The base of the profile is 100 km and computations are made at 5 km increments to 1000 km. The three regions are added together to give the total electron density at each increment of altitude. Electron density is not permitted to decrease with altitude, but is held constant across "valleys" in the profile.

Total electron content in a one square meter cross section up to a given altitude is also computed. An initial electron content is established at 95 km, to represent the total content below 100 km. A calculation of plasma frequency is made from the electron density for each 5 km interval.

Input parameters are read from data cards. The first data card indicates output options (Table 1). The second data card contains information pertaining to the geographic location of the profile. The format of the card is the same for all input options (Table 2).

As previously mentioned, there are three input options which determine the method by which $f_0 F_2$ and $M(3000)$ are introduced into the program. Data card number 3 contains information pertinent to the profile, including the input option variable IOPT. Table 3 lists the input parameters on the third data card and indicates which of them are used by the program under each of the three input options. If IOPT = 1, $f_0 F_2$ and $M(3000)$ are computed from a card deck of ITS Prediction Coefficients. (Subroutines used to compute $f_0 F_2$ and $M(3000)$ from ITS coefficients were extracted from a program published in [4].) If IOPT = 2, a long-term data tape containing sunspot dependent coefficients of $f_0 F_2$ and $M(3000)$ is read to determine $f_0 F_2$ and $M(3000)$. Finally, if IOPT = 3, $f_0 F_2$ and $M(3000)$ are read explicitly from the data card.
### TABLE 1

<table>
<thead>
<tr>
<th>Card Column</th>
<th>Variable</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>IPLT</td>
<td>If IPLT = 1, a profile of plasma frequency vs height is plotted. If IPLT = 0, plot is suppressed.</td>
</tr>
<tr>
<td>2</td>
<td>IPNCH</td>
<td>If IPNCH = 1, the 17 most significant points depicting the profile are punched onto data cards. If IPNCH = 0, the punch routine is suppressed.</td>
</tr>
</tbody>
</table>

### TABLE 2

<table>
<thead>
<tr>
<th>Card Column</th>
<th>Variable</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-6</td>
<td>CLAT</td>
<td>Latitude</td>
</tr>
<tr>
<td>7</td>
<td>NORS</td>
<td>Hemisphere (N, S)</td>
</tr>
<tr>
<td>8-13</td>
<td>CLONG</td>
<td>Longitude</td>
</tr>
<tr>
<td>14</td>
<td>IHEM</td>
<td>Hemisphere (E, W)</td>
</tr>
<tr>
<td>15-38</td>
<td>NAME</td>
<td>Name of Station</td>
</tr>
<tr>
<td>Card Column</td>
<td>Variable</td>
<td>Required Under Option</td>
</tr>
<tr>
<td>------------</td>
<td>----------</td>
<td>-----------------------</td>
</tr>
<tr>
<td>1-2</td>
<td>IYR</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>3-4</td>
<td>MNTH1</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>5-6</td>
<td>MNTH2</td>
<td>1, 2</td>
</tr>
<tr>
<td>7-8</td>
<td>IDA</td>
<td>3</td>
</tr>
<tr>
<td>9-12</td>
<td>IBHR</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>13-16</td>
<td>IEHR</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>17-18</td>
<td>INC</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>19-21</td>
<td>JDAY</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>22</td>
<td>IOPT</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>26-30</td>
<td>SSN</td>
<td>1, 2, 3</td>
</tr>
<tr>
<td>31-40</td>
<td>F0F2</td>
<td>3</td>
</tr>
<tr>
<td>41-50</td>
<td>EM3000</td>
<td>3</td>
</tr>
<tr>
<td>51-56</td>
<td>IVB</td>
<td>1, 2</td>
</tr>
<tr>
<td>57-62</td>
<td>IVE</td>
<td>1, 2</td>
</tr>
</tbody>
</table>

NOTE: All numbers are integers except SSN, F0F2, and EM3000. These three are floating point, punched with a decimal point, anywhere in the field.
V. Description of the Computer Produced Profile.

Appendix 2 is a sample profile produced by computer. The profile is in four sections. The first section provides a summary of input data and pertinent information for each of the three regions. The second section is the profile itself, listing values of height, E-region density, F1-region density, F2-region density, total density, cumulative electron content, plasma frequency and scale height for each 5 km increment of the model. Output of the third section depends upon the value of the output option IPILOT (see Table 1), and plots a graph of plasma frequency vs height for the model. The fourth and final section depends upon the value of the output option IPNCH. If selected, the 17 most significant values of plasma frequency describing the profile are chosen objectively and written onto magnetic tape for punching onto data cards. In addition, a checklist of the points selected is printed.

VI. Evaluation of the Model.

An evaluation of this model was made by comparing with observed electron density profiles and with total electron content measurements.

Figures 1 to 8 show model monthly median profiles for Wallops Island, Va., during 1968, compared with the observed profiles available from World Data Center A, Boulder, Colorado. Excellent results are obtained during winter and at night. The July 1800Z (mid-day) is the worst case among several dozen such comparisons at various locations and times.

In Table 4, the total electron content calculated to 1000 km is compared with observations of total content from Bedford, Mass., to geostationary satellites, a path which passes through the F2 peak near Wallops Island. These observations, courtesy of Jack Klobuchar, Air Force Cambridge Research Laboratories, are converted to vertical incidence by assuming a cosine correction factor. As expected, the model is generally lower than the observations since it cuts off at 1000 km. It is interesting to note that in the summer daytime, when the model overestimates the bottomside content (Figure 6), it underestimates the total content. This implies that more electrons are present in the topside than the model predicts.

A third comparison is shown in Figure 9. Here, total content to 1000 km from the model is compared with the total content on near vertical incidence paths to synchronous satellites in the vicinity of Hawaii [5]. The shape of the diurnal curve is good and the results are again excellent at night but are underestimated at midday.
<table>
<thead>
<tr>
<th>GMT</th>
<th>OBSERVED TEC</th>
<th>MODEL TO 1000 KM</th>
<th>PERCENT DIFFERENCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0100</td>
<td>1.2</td>
<td>1.0</td>
<td>-10</td>
</tr>
<tr>
<td>0500</td>
<td>.66</td>
<td>.56</td>
<td>-15</td>
</tr>
<tr>
<td>2000</td>
<td>4.1</td>
<td>3.5</td>
<td>-15</td>
</tr>
<tr>
<td>March</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0200</td>
<td>1.6</td>
<td>1.4</td>
<td>-13</td>
</tr>
<tr>
<td>0500</td>
<td>.98</td>
<td>.95</td>
<td>-3</td>
</tr>
<tr>
<td>1100</td>
<td>.65</td>
<td>.61</td>
<td>-3</td>
</tr>
<tr>
<td>1600</td>
<td>3.3</td>
<td>3.2</td>
<td>-3</td>
</tr>
<tr>
<td>2100</td>
<td>3.7</td>
<td>3.4</td>
<td>-8</td>
</tr>
<tr>
<td>May</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0300</td>
<td>1.5</td>
<td>1.4</td>
<td>-7</td>
</tr>
<tr>
<td>0700</td>
<td>.85</td>
<td>.93</td>
<td>+9</td>
</tr>
<tr>
<td>1200</td>
<td>3.4</td>
<td>3.2</td>
<td>-14</td>
</tr>
<tr>
<td>1600</td>
<td>2.3</td>
<td>2.0</td>
<td>-13</td>
</tr>
<tr>
<td>2100</td>
<td>2.7</td>
<td>2.1</td>
<td>-22</td>
</tr>
<tr>
<td>July</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0400</td>
<td>1.2</td>
<td>1.1</td>
<td>-8</td>
</tr>
<tr>
<td>0800</td>
<td>.62</td>
<td>.60</td>
<td>-3</td>
</tr>
<tr>
<td>1300</td>
<td>1.4</td>
<td>1.3</td>
<td>-7</td>
</tr>
<tr>
<td>1800</td>
<td>1.8</td>
<td>1.6</td>
<td>-11</td>
</tr>
<tr>
<td>2300</td>
<td>2.1</td>
<td>1.6</td>
<td>-24</td>
</tr>
<tr>
<td>September</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0100</td>
<td>1.4</td>
<td>1.4</td>
<td>0</td>
</tr>
<tr>
<td>0500</td>
<td>.91</td>
<td>.89</td>
<td>-2</td>
</tr>
<tr>
<td>1000</td>
<td>.42</td>
<td>.46</td>
<td>+10</td>
</tr>
<tr>
<td>1500</td>
<td>2.4</td>
<td>2.4</td>
<td>0</td>
</tr>
<tr>
<td>2000</td>
<td>2.9</td>
<td>2.7</td>
<td>-7</td>
</tr>
<tr>
<td>November</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0200</td>
<td>.75</td>
<td>.65</td>
<td>-13</td>
</tr>
<tr>
<td>0600</td>
<td>.55</td>
<td>.52</td>
<td>-9</td>
</tr>
<tr>
<td>1100</td>
<td>.39</td>
<td>.36</td>
<td>-8</td>
</tr>
<tr>
<td>1600</td>
<td>3.2</td>
<td>3.3</td>
<td>+3</td>
</tr>
<tr>
<td>2100</td>
<td>3.2</td>
<td>2.8</td>
<td>-13</td>
</tr>
</tbody>
</table>
VII. Summary and Conclusion.

The electron density profile model came about as an attempt to produce a reasonably simple method of predicting electron densities in the 100-1000 km range. This model should not be considered final, by any means, even for the current applications. The scale height profile should be improved to include diurnal and seasonal variations. The model should be extended from its upper limit of 1000 km to the plasmapause. Variations of electron density with geomagnetic activity should be included. Improved prediction or specification of any of the input parameters will, of course, improve the accuracy of the profile model. The height of the F2 maximum is probably the most important of these.
VIII. References.


Appendix A

Computer Program
"MODEL"
**SIHFTIC MODEL**

*DIMENSION SCALE(182), IHGT(182)*

*DIMENSION VAL(91), NAME(4), STOR(182)*

**COMMON K1(14), U1(17, 76), X1(17, 76), K1(14), KX1(14),**

**DATA I'E, IS/IHE, IHS/*

C

**** SET UP CONSTANTS FOR RADIAD CONVERSION ******

C

C180 = 3.1415927
P12 = C180/2.0
AK = C180/180.0
UK = 180.0/C180
GLT = 1.36135662
GLG = 1.22173030
KARL = C

C

C**** SCALE HEIGHT COMPUTATION (WROBEL'S EQUATION) ******

C

H = 95.
CO Id. = 1, 182
SCALE(1) = ALOG (H) / 2.186E-02 - 203.447
IHGT(1) = H
IF (I.EQ.1) SCALE(1) = 6.6
10 H = H + 5.0
C

C**** READ OUTPUT OPTIONS ******

C

READ (5, 11) I PLOT, IPNC

11 FORMAT (211)

C

C**** READ LOCATION OF STATION ******

C

READ (5, 4) CLAT, NORS, CLONG, IHEM, (NAME(I), I = 1, 4)

4 FORMAT (2(F6.1, A1, 4A6)

C

C**** CHECK FOR BLANK CARD (END OF ALL DATA) ******

C

IF (CLAT.EQ.0.0) GO TO J77

C

C**** CHECK FOR EASTERN OR SOUTHERN HEMISPHERE ******

C

IF (NORS.EQ.IS) CLAT = -1.0*CLAT
IF (IHEM.EQ.1E) CLONG = -1.0*CLONG

8000 READ (5, 44) I YR, MTH1, MTH2, I EA, IBHR, IEHR, INC, JDAY, I OPT, SSN, FC F2,

I E3000, TVB, I VE

44 FORMAT (412, 214, 12, 13, 11, 3X, F5.1, 2F10.5, 2A6)

I YR, IBHR

INC = INC + 100

C

C**** CHECK OPTION 1 = ITS COEFFICIENTS READ FROM CARUS
C

C 2 = LONG TERM DATA TAPE
C

C 3 = FC F2 AND M(3000) EXPLICIT ******

23
IF(IOPT.EQ.1.AND.KARU.EQ.0) GO TO 1
IF(IOPT.EQ.1.AND.KADO.EQ.1) GO TO 34
IF(IOPT.EQ.2) GO TO 2
IF(IOPT.EQ.3) GO TO 3
GO TO 33
C
C******** IOPT = 1, READ CARDS ********
C
1 CALL READU(K,UI)
CALL READU(KX,UX)
IF(MNTH2.GT.0) CALL READU(K1,U1)
IF(MNTH2.GT.0) CALL READU(KX1,UX1)
KARU=1
GO TO 34
C
C******** IOPT = 2, READ LONG-TERM DATA TAPE ********
C
2 CALL LTape(MNTH1,SSN,K,UX,KX,UX1)
IF(MNTH2.GT.0) CALL LTape(MNTH2,SSP,K1,U1,KX1,UX1)
GO TO 34
CONTINUE
800 CALL Digi(CLAT,CLONG,1HR,FOF2,EM3000,MNTH1,MNTH2)
GO TO 3
33 WRITE (6,333)
333 FORMAT (1H1,3H0R0,9N10)
GO TO 777
J CONTINUE
C
C******** IOPT = 3, BEGIN COMPUTATIONS ********
C
C******** NOW HAVE FOF2 AND M3000 BY ONE OF THREE METHODS ********
C
C******** CALCULATE SOLAR ZENITH ANGLE ********
C
IF(RST=1HR/10C
SECOND=1HR-IFRST*1C0
SECU=SECOND/60.
GMT=FLCAT(IFRST)+SECNC
IF(GMT.EC.0.00 GMT=24.
J=JDAY
SSP=-23.45*COS(IU+10.1/365.0)+180.*2.
SSL=15.0*GMT-180.0
Z=SSL-CLONG*AK
COMP=SIN(CLAT*AK)*SIN(SSP)+COS(CLAT*AK)*COS(SSP)*COS(Z)
COMP=ARCCOS(COMP)
COMP=ABS(COMP)
RANG=COMP
ZANG=COMP*8K+0.5
C
C CALCULATE GEOMAGNETIC LATITUDE
C
}24
GAT = \arccos (\sin (GLT) \cdot \sin (CLAT \cdot AK) + \cos (GLT) \cdot \cos (CLAT \cdot AK) \cdot \cos (CLONG \cdot AK - GLG))

GLAT = (\pi - GAT) \cdot HK

R = SSN

***** NOW HAVE NEEDED PARAMETERS FOR EQUATIONS *****

***** HEIGHT OF E-REGION SET TO 120 KM *****

HE = 120.0

***** COMPUTE SCALE HEIGHT OF E-REGION *****

TE = (\text{ALOG}(HE)/2.186E-02)-203.447

***** COMPUTE FOE *****

PART = 0.9*((180.0+1.44*HK)*\cos (RANG))

IF(PART.GE.0.0) FOE = PART*0.25
IF(PART.LT.0.0) FOE = 0.7

***** IF SOLAR ZENITH ANGLE GREATER THAN 130 DEG, FOE SET TO 0.3 *****

IF(ZANG.GL.130.) FOE = 0.3

***** IF SOLAR ZENITH ANGLE GREATER THAN 90 DEG, FOE SET TO 0.7 *****

IF(ZANG.GL.90.0) FOE = 0.7

***** COMPUTE FOFl *****

FOFl = 1.26*FOE^0.5

***** COMPUTE MAX DENSITY OF E-REGION *****

\text{EN}E = 1.24E04*(FOE)**2

***** COMPUTE MAX DENSITY OF F1-REGION *****

\text{FN}MAX = 1.24E04*(FOF1)**2

***** COMPUTE MAX DENSITY OF F2-REGION *****

\text{EN}MAX = 1.24E04*(FOF2)**2

***** COMPUTE HEIGHT OF MAX DENSITY (SHIMAZAKI EQUATION) *****

HMAX = 1490.0/EM3000-176.0

***** COMPUTE SCALE HEIGHT OF F2-REGION *****

TF = (\text{ALOG}(HMAX)/2.186E-02)-203.447

25
C
C******** HEIGHT OF FL-REGION SET TO MIDPOINT OF E- AND F2-ROGSIONS ******
C
C
C******** COMPUTE SCALE HEIGHT OF FI-REGION ******
C
TFI=\{1\LOG(HMAXI)/2,186e=2}\-203,447
IF\{ILOPT.EQ.1\} WRITE \{6,990\} IV8,IVE,LYR,IRHR
IF\{ILOPT.EQ.3\} WRITE \{6,99\} FYR,WNTH,IDA,IRK
C
C******** OUTPUT SECTION ******
C
C
C******** HEADING FOR SUMMARY PAGE ******
C
990 FORMAT (1H1,26HIONOSPHERIC PROFILE VALID,A6,2X,A6,2X,12,15,1HZ)
99 FORMAT (1H1,24HIONOSPHERIC PROFILE FOR,A6,2X,15,1HZ)
WRITE (6,100) CLAT,NORS,CLONG,ICEM,(NAME(I),I=1,4)
1100 FORMAT (1H1,17HSTATION LOCATION ,2TF6.1,A11//15X,4A6)
1FTILOPT.EQ.1) WRITE (6,1000)
1FTILOPT.EQ.2) WRITE (6,1001)
1001 FORMAT (1H0,3HTHIS PROFILE BASED UPON LONG-TERM DATA TAPE)
1000 FORMAT (1H0,7X,40HTHIS PROFILE BASED UPON ITS COEFFICIENTS)
WRITE (6,10) CLAT,NORS,CLONG,R
10 FORMAT (1H0,7HFOF = ,F*,2,10X,8HM3000 = ,F5.2,10X,6HFOE = ,F7.2,10X,7HFHF = ,F7.2)
WRITE (6,103) TE,HE,ENE
103 FORMAT (1H0,7HFOF = ,F*,2,10X,8HM3000 = ,F5.2,10X,6HFOE = ,F7.2,10X,7HFHF = ,F7.2)
WRITE (6,104) TF1,HMAX1,FNMNN
104 FORMAT (1H0,2OHVALUES FOR FL-REGION//
15X,15HSCLAE HEIGHT =,F7.2,3H KM/
25X,9HMHEIGHT = ,F7.2,3H KM/
35X,10DENSITY = ,FR.0,13H ELECTRONS/CC)
WRITE (6,10) CLAT,NORS,CLONG,R
10 FORMAT (1H0,7HFOF = ,F*,2,10X,8HM3000 = ,F5.2,10X,6HFOE = ,F7.2,10X,7HFHF = ,F7.2)
WRITE (6,103) TE,HE,ENE
103 FORMAT (1H0,7HFOF = ,F*,2,10X,8HM3000 = ,F5.2,10X,6HFOE = ,F7.2,10X,7HFHF = ,F7.2)
WRITE (6,104) TF1,HMAX1,FNMNN
104 FORMAT (1H0,2OHVALUES FOR F1-REGION//
15X,15HSCLAE HEIGHT =,F7.2,3H KM/
25X,9HMHEIGHT = ,F7.2,3H KM/
35X,10DENSITY = ,FR.0,13H ELECTRONS/CC)
WRITE (6,10) CLAT,NORS,CLONG,R
10 FORMAT (1H0,7HFOF = ,F*,2,10X,8HM3000 = ,F5.2,10X,6HFOE = ,F7.2,10X,7HFHF = ,F7.2)
WRITE (6,103) TE,HE,ENE
103 FORMAT (1H0,7HFOF = ,F*,2,10X,8HM3000 = ,F5.2,10X,6HFOE = ,F7.2,10X,7HFHF = ,F7.2)
WRITE (6,104) TF1,HMAX1,FNMNN
104 FORMAT (1H0,2OHVALUES FOR F2-REGION//
15X,15HSCLAE HEIGHT =,F7.2,3H KM/
25X,9HMHEIGHT = ,F7.2,3H KM/
35X,10DENSITY = ,FR.0,13H ELECTRONS/CC)
C******** WRITE HEADING FOR PROFILE PAGE ******
C
201 FORMAT (1H1,10X,24HELECTRON DENSITY PROFILE//5X,2HKM,5X,
1RF-REGION,5X,SHFI-REGION,5X,9HF2-REGION,TX,5HTOTAL,TX,
210HOMATIC,5X,16HPLASMA FREQUENCY,5X,5HSCALE)
ENP1=0.
ENSNAV=0.

20
**C** ****COMPUTE AND PRINT VALUES FOR EACH > KM LEVEL** ****

```c
J=95;
IH=240 I=1,182
J=1/2
FZE=(H-HMAX)/TF1
EZE=(H-HE)/TE
```

**C** ****ELECTRON DENSITIES COMPUTED FOR F2-REGION BASED ON A**

**C** ****CONSTANT SCALE HEIGHT IF BELOW THE F2-PEAK AND**

**C** ****ON A VARIABLE SCALE HEIGHT IF ABOVE THE F2-PEAK** ****

```c
ENP=EN=EF+FN
IF(H.GT.HMAX) ZEE=(H-HMAX)/SCALE(1)
IF(H.LE.HMAX) ZEE=(H-HMAX)/TF
EE=ENE * EXP(0.5* (1.0-EZE * EXP(-1.0*EZE)))
EN=ENMAX * EXP(1.0-ZEE * EXP(-1.0*EZE))
FN=FNMAX * EXP(1.0-FZE * EXP(-1.0*FZE))
```

```c
ENP=EN+ENP1
PLAS=8.97E-03 * SQRT(ENP)
STOR(I)=PLAS
IF(MOD(I,2).EQ.0) VAL(J)=PLAS
ENS=N+ENS+ENP*5.00E3
IF(I.EQ.1) GO TO 200
```

```c
IH=H
WRITE (6,202) IH, EE, FN, EN, ENP, ENSAV, PLAS, SCALE(I)
```

```c
202 FORMAT (3X,14,IX,4<4X,F9.0),5X,
```

```c
2C0   H=H+5.0
```

**C** ****CALL PLOT ROUTINE IF REQUESTED** ****

```c
IF(I.PLOT.GT.0) CALL PLOT(VAL)
```

**C** ****CALL PUNCH ROUTINE IF REQUESTED** ****

```c
IF(I.PUNCH.GT.0) CALL SIG(STOR, IHRT, IVB, IVF, TBR, THT)
```

**C** ****IF IOPT EQUALS 3, ONLY ONE STATION ANALYZED PER FUF2 AND M13000**

```c
IF(IOPT.EQ.3) GO TO 999
```

**C** ****INCREMENT HOUR** ****

```c
IH=IH+INC
IF(IH.GT.IEH) GO TO 999
```

```c
```

**C** ****EXIT AND TERMINATE RUN** ****

```c
777 CONTINUE
ENDFILE 9
REWIND 9
STOP
```

```c
END
```

27
**$IBFTC CURVE**

SUBROUTINE PLOT(VAL)

INTEGER GRU(46), ABSC(46), FREQ(46)

INTEGER EYE, BLANK, DOT, DASH, EX

REAL VAL(91)

DATA EYE, BLANK, DOT, DASH, EX/1H, 4H, 7H, 10H, 13H/,

DATA (ABSC(I), I=1,46)/1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

2H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

3H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

4H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

5H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

6H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

7H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

8H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

9H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

10H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H, 1H,

LOC=3,0+VAL(I)+1.6

GRID(LOC, I)=EX

WRITE (6, 50)

FORMAT (1HL1, 40X, 10HEIGHT[KM])

WRITE (6, 51)

FORMAT (10X, 10X, 5X, 10X, 5X)

WRITE (6, 52)

FORMAT (10X, 10X, 5X, 10X, 5X)

WRITE (6, 53)

FORMAT (10X, 10X, 5X, 10X, 5X)

WRITE (6, 54)

CONTINUE

RETURN

END
SUBROUTINE SIG(STOR, IHGT, IV8, IVE, IY8, IHR)

INTEGER HEIT(17)
HEIT(1)=IHGT(2)
HEIT(2)=IHGT(6)
HEIT(15)=IHGT(182)
HEIT(16)=IHGT(22)
PLASQ(6)=STOR(2)
PLASQ(17)=STOR(182)
HEIT(17)=IHGT(32)
PLASQ(1)=STOR(12)
PLASQ(17)=STOR(182)
CONTINUE
HEIT(3)=IHGT(12)
PLASQ(3)=STOR(12)
K=12
GO TO 5
HEIT(3)=IHGT(1)
PLASQ(3)=STOR(1)
K=1
DO 6 I=K,181
IF(STOR(I+1).NE.STOR(I)) GO TO 7
CONTINUE
HEIT(4)=IHGT(22)
PLASQ(4)=STOR(22)
K=22
GO TO 8
HEIT(4)=IHGT(1)
PLASQ(4)=STOR(1)
K=1
DO 9 I=K,181
IF(STOR(I).LT.STOR(I+1)) GO TO 9
HEIT(7)=IHGT(1)
PLASQ(7)=STOR(1)
GO TO 10
CONTINUE
K=1-5
L=1-LG
LL=L+4
HEIT(8)=IHGT(LL)
HEIT(6)=IHGT(K)
HEIT(5)=IHGT(LL)
PLASQ(8)=STOR(LL)
PLASQ(6)=STOR(K)
PLASQ(5)=STOR(L)
HEIT(9)=IHGT(52)
CONTINUE
GO TO 11
PLASQ(9) = STOK(52)
K = 62
IF (HEIT(9).GT.370) K = 72
HEIT(10) = HGT(K)
PLASQ(10) = STOR(K)
HEIT(11) = HGT(82)
PLASQ(11) = STOR(82)
HEIT(12) = HGT(102)
PLASQ(12) = STOR(102)
HEIT(13) = HGT(132)
PLASQ(13) = STOR(132)
HEIT(14) = HGT(162)
PLASQ(14) = STOR(162)

IF (HEIT(1).GE.HEIT(1-1)) GO TO 100
ITEMP = HEIT(1)
HEIT(1) = HEIT(1-1)
HEIT(1-1) = ITEMP
TEMP = PLASQ(1)
PLASQ(1) = PLASQ(1-1)
GO TO 15

CONTINUE
IHR1 = IHR - 70
IF (IHR1.LT.0) IHR1 = 2330
IHR2 = IHR + 30
IHR1 = IHR1 + 10000
WRITE (9, 99) IV8, IYR, IVE, IYR, IHR1, IHR2
WRITE (6, 98) IV8, IYR, IVE, IYR, IHR1, IHR2
99 FORMAT (6VALID, A6, 13, 3H = , A6, 13, 1X, 14, 9HZ TO , 14,
13HZ REMOVE THIS CARD BEFORE USING)
98 FORMAT (1H1, 26HIONOSPHERIC PROFILE VALID , A6, 13, 3H = , A6, 13, 1X, 14,
15HZ TO , 14, 1HZ)
DO 260 I = 1, 17
WRITE (5, 97) HEIT(I), PLASQ(I)
WRITE (9, 96) HEIT(I), PLASQ(I)
260 CONTINUE
97 FORMAT (1X, 4H1CNC, 12X, 14, F12.2)
96 FORMAT (4HIONO, 12X, 14, F12.2)
RETURN
END
Appendix B

Sample Computer Output
STATION LOCATION 24°04' R6°0W

EGLIN RANGE

THIS PROFILE BASED UPON ITS COEFFICIENTS

\[
\begin{align*}
\text{F0F2} &= 3.25 \\
\text{M3000} &= 2.76 \\
\text{F0} &= 4.04 \\
\text{FMF1} &= 5.59 \\
\end{align*}
\]

GEOMAGNETIC LATITUDE = 35.49° SOLAR ZENITH ANGLE = 18.11°

SUNSPOT NUMBER = 90.

VALUES FOR F-REGION

\[
\begin{align*}
\text{SCALE HEIGHT} &= 15.56\,\text{KM} \\
\text{HEIGHT} &= 120.00\,\text{KM} \\
\text{DENSITY} &= 202070\,\text{ELECTRONS/CC} \\
\end{align*}
\]

VALUES FOR F1-REGION

\[
\begin{align*}
\text{SCALE HEIGHT} &= 47.56\,\text{KM} \\
\text{HEIGHT} &= 241.54\,\text{KM} \\
\text{DENSITY} &= 346389\,\text{ELECTRONS/CC} \\
\end{align*}
\]

VALUES FOR F2-REGION

\[
\begin{align*}
\text{SCALE HEIGHT} &= 66.21\,\text{KM} \\
\text{HEIGHT} &= 381.07\,\text{KM} \\
\text{DENSITY} &= 106182\,\text{ELECTRONS/CC} \\
\end{align*}
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This paper describes a project undertaken by 4th Weather Wing to produce a realistic electron density profile based upon parameters which can be forecast with reasonable accuracy. The ionospheric electron density profile model presented in this paper consists of the sum of three Chapman layers (E, F1, F2). Electron densities in the topside ionosphere are controlled by complex motions rather than a production-loss balance and cannot be successfully described strictly by a Chapman layer. After some experimentation a best fit was obtained by simply using the Chapman equation for the topside ionosphere, but computing the electron densities by using a variable scale height throughout the region. The program described in this report has been used routinely for eight months to predict profiles for radar refraction. This report should be considered interim as improvements in accuracy are sure to be required as the model is evaluated for different purposes.