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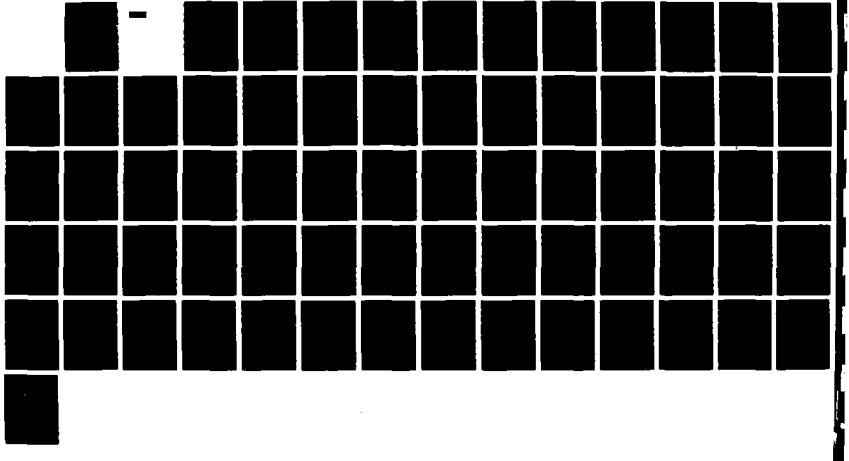

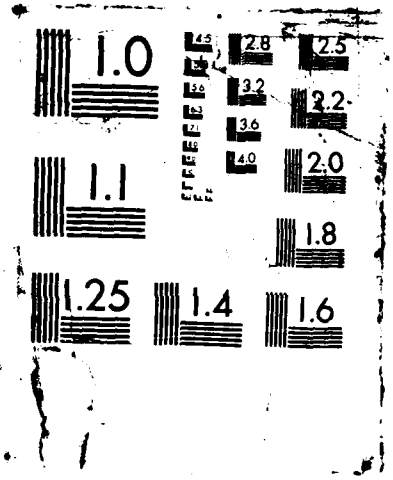
1.0
2.8
2.5
3.2
2.2
3.6
4.0
2.0
1.1
1.8
1.25
1.4
1.6

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Implementation of a full-wave fields program developed for calculations at ELF is described. The program incorporates modifications to the original code for use at VLF, including allowance for multiple modes. Other changes relate to improving compatibility of the basic program setup with that of other programs in the Defense Nuclear Agency repertoire.

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## INTRODUCTION

This report describes the implementation of a full-wave fields program developed for calculations at ELF (Pappert and Shockey, 1977). The program to be described here incorporates modifications to the original code for use at VLF, including allowance for multiple modes. Other changes relate to improving compatibility of the basic program setup with that of other programs in the Defense Nuclear Agency repertoire.

The program is written in VAX FORTRAN for use with Digital Equipment Corporation's VAX/VMS operating systems. VAX FORTRAN is based on American National Standard FORTRAN-77 (ANSI X3.9-1978) and includes support for programs that conform to the previous standard (ANSI X3.9-1966) as well as numerous extensions to the ANSI standard. The WAVFLD program uses some extensions of the ANSI standard, including namelist-directed input/output and additional data typing, such as COMPLEX*16.

## DESCRIPTION OF INPUT

### PROGRAM CONTROL

Program execution is controlled by a series of character strings which indicate the type of data to follow. The control strings must begin in column one of the record and can be in uppercase or lowercase letters. The ionospheric and collision frequency profiles can be input by either of two different methods. If either profile is strictly exponential, it can be read in by means of variables in the NAMELIST input signaled by the control string NAME. If either profile is non-exponential, it must be read in by means of a tabular-type formatted input signaled by the PROFILE or COLFREQ control strings. All of these control strings are described below, and are summarized in Table 1.

Table 1. Summary of control strings.

| | |
|---|---|
| NAME | initiates reading of NAMELIST input |
| PROFILE | initiates reading of ionospheric profile |
| COLFREQ | initiates reading of ionospheric collision-frequency profile |
| DATA | initiates reading of propagation path data |
| SW XMT | provides same function as DATA |
| QUIT | indicates end of the input |

NAME — Signals that NAMELIST data follow. In this program the NAMELIST name is DATUM. The NAMELIST variables are described in the next section.

PROFILE — Initiates reading of the ionospheric charged-particle profile data used to model the upper boundary of the earth-ionosphere waveguide. This allows for using a non-exponential ionospheric profile. The PROFILE control string is followed by an alphanumeric record, which is used to identify the profile. It can contain up to 80 characters of information. The profile is input starting at the top of the ionosphere, and the records must be input in descending order of height. The profile records contain the height, in kilometers, and the species densities, in particles per cubic centimeter, at that height. A format of [F7.2,4X,5(1X,E9.2)] is used to read the records. In the integration of the reflection elements through the ionosphere, the program interpolates exponentially between input values. The profile should contain sufficient data to define the ionospheric structure with height. For example, an exponential profile should consist of only the top and bottom heights and densities. Many regularly spaced heights tend to slow the integration. A purely exponential ionospheric profile (electrons only) may also be specified in the NAMELIST input by the variables BETA, HPRIME, and SCLHTS. A maximum of 101 heights can be specified and a maximum of five species per height may be input. The number of species to be used is determined from

the control string. If the ninth column is blank, one species is assumed. If a value is in this column, it is used for the number of species. In the special case of three species, only two species are specified at each altitude. The first is assumed to be electrons and the second positive ions. The third species, negative ions, is calculated in the program by subtracting the electron density from the positive-ion density to preserve charge neutrality. All three species are listed in the output. If the value of any species is less than 1.0d-20, it is set to that value. The end of the profile is indicated by a height less than zero.

COLFREQ Initiates reading of the collision-frequency profile via tabular input. This allows for use of a non-exponential collision frequency. If the tabular input is used, it overrides the NAMELIST variables COEFNU and EXPNU. Collision frequencies for all species must be input. The ionospheric profile must precede the collision-frequency profile because the number of species to be used is determined from the PROFILE control string. As with the ionospheric species profiles, the profile is input starting at the top of the ionosphere, the records must be input in descending order of height, and the program interpolates exponentially between input values. There need be no correspondence between the altitudes used to define the charged-particle profile and the collision-frequency profile. Also, any species value less than 1.0d-20 is replaced by that value, the same format is used to read the records, and the end of the profile is indicated by a height less than zero. The profile records contain the height in kilometers and the collision frequencies in collisions per second. A maximum of 25 heights can be specified, and a maximum of 5 species per height may be input. A strictly exponential collision frequency may be specified in the NAMELIST input by the variables COEFNU and EXPNU.

DATA Signals that the propagation-path data follow. The format of these data is that which is produced by MODEFNDR (Shellman, 1986) and the SEGMENTED WAVEGUIDE PROGRAM (Ferguson and Snyder, 1987). The first record contains the data set identification. This is followed by sets of mode constants, one for each path segment. The first record for each segment contains the starting distance, frequency, magnetic azimuth, codip, and intensity, and the ground conductivity and permittivity. This record is followed by the mode-constant records, one pair for each mode, containing the following information:

```
1  THETA I   T1  T2
2  THETA I   T3  T4,
```

where 1 and 2 are sequencing indices and THETA is the complex eigenangle at the ground. For a discussion of I and the four T quantities, see Ferguson and Snyder, 1980. The list of modes for each segment is terminated by a

blank record. After reading the data for each segment, the program begins the WAVFLD calculations. The list of segments is terminated by a record with the starting distance set equal to 40.0.

SW XMT Provides the same function as DATA control string.

QUIT Indicates the end of the input. The execution of the program is terminated.

**NAMELIST VARIABLES**

The NAMELIST variables are described in tabular form below. The initial or default values are given in Table 2.

Table 2. Namelist variables and initial values.

| Name | Value | Units |
|---|---|---|
| nprof | 0 | - |
| beta | 0.0 | 1/km |
| hprime | 0.0 | km |
| sclhts | 5.0 | |
| h | 0.0 | km |
| alpha | 3.14e-4 | 1/km |
| prec | 3.0e-5 | |
| debug | 0 | - |
| nelect | 0 | - |
| coefnu | 1.816e11,4*4.54e9 | coll/sec |
| expnu | 5*-0.15 | 1/km |
| charge | -1.0,1.0,-1.0,1.0,-1.0 | |
| mratio | 1.0,4*5.8e4 | |
| topht | 100.0 | km |
| lwstht | 0.0 | km |
| itr | 0 | - |
| maxitr | 10 | - |
| dtheta | (5.0d-2,1.0d-2) | degrees |
| lub | (5.0d-2,5.0d-3) | degrees |
| nprint | 1 | - |
| savplt | .true. | - |

NPROF — A flag controlling usage of exponential electron-density profile. Setting the flag non-zero indicates usage of exponentiai electron-density profile. Setting the flag to zero indicates non-usage of exponential electron-density profile.

BETA — The height variation of the electron density for exponential ionospheric profiles in inverse kilometers.

HPRIME — The reference height of the electron density for exponential ionospheric profiles in kilometers.

SCLHTS — The number of scale heights above HPRIME at which the top of the exponential electron-density profile is defined.

H — Altitude in kilometers at which the modified refractive index is unity.

ALPHA — Earth curvature coefficient in inverse kilometers. ALPHA is defined as 2/radius of the earth. For a flat earth, use ALPHA = 0.

PREC — Accuracy to be maintained locally in the numerical integrations. It is usually taken to be the default value of 3.0e-5.

DEBUG — A flag controlling the amount of diagnostic output desired.

| | |
|---|---|
| DEBUG = 0 | suppress all printout |
| DEBUG = 1 | print height gains |
| DEBUG = 2 | print information on initial boundary conditions and number of integration steps |
| DEBUG = 3 | print extensive debug output |

COEFNU — The collision frequency, in collisions per second, at the ground. It is used with EXPNU to specify an exponential collision frequency.

EXPNU — The height variation in inverse kilometers. It is used to specify an exponential collision frequency.

CHARGE — The charge of each species. For an electron the charge is -1.

MRATIO — The ratio of the mass of the species to the mass of an electron. For an electron, the ratio is 1.

TOPHT — Greatest height in the ionosphere where field strengths are desired.

LWSTHT — Lowest height in the ionosphere where field strengths are desired.

ITR — A flag to control iterations. If ITR = 1, iterations are performed to refine the input eigenangle (THETA).

MAXITR — The maximum number of iterations allowed in finding a modal solution. The iterations are terminated for the current angle when MAXITR is exceeded.

DTHETA — The complex incremental change in the modal solution for computing the derivative. It is input as a pair of real numbers.

LUB — A complex number used to terminate the iterative process. The real and imaginary parts of LUB are used to test the iterative change in the real and imaginary parts of the modal solution. The iteration is stopped when the change is less than or equal to LUB in both real and imaginary parts. It is input as a pair of real numbers.

NPRINT — A flag controlling the amount of output.

| | |
|---|---|
| NPRINT = 0 | no output is generated. |
| NPRINT = 1 | the total fields are printed. |
| NPRINT = 2 | the individual modes are printed. |

SAVPLT — A logical flag for writing data to logical unit 10 for further processing and/or plotting. This variable allows the user to submit batch or background jobs to generate the data to be plotted.

| | |
|---|---|
| SAVPLT = .TRUE. | data are written |
| SAVPLT = .FALSE. | no data are written |

## SAMPLE PROBLEM

A sample case will be discussed. The data for this case were generated using MODEFNDR (Shellman, 1986). The printed output for this MODEFNDR run is shown in Figure 1. This figure is included here so the user may see the correspondence between inputs to MODEFNDR and the inputs to WAVFLD (shown in Figure 2). The profile specifications are identical in the two programs. The data lines between 'DATA' and the blank line just before 'R 40' are all output from MODEFNDR. Immediately after the DATA control string is the data identification string which followed the ID string in Figure 1. The frequency, geomagnetic field parameters, and ground conductivity parameters are encoded in the line after the identification string. This is followed by pairs of lines containing the mode parameters.

The printed output from WAVFLD is shown in Figure 3. This output shows the ionospheric profile data and the values of the NAMELIST variables. After the DATA control string, the parameters of the individual modes are shown. Initially, the basic parameters of attenuation rate, normalized phase velocity, and excitation factor are printed. The number of integration steps for one integration and the resulting value of the complex mode equation are printed. The sample case calls for iteration of the input eigenangles, so the integrations continue until the incremental change in the eigenangle is less than LUB. For the first mode, this happens after two iterations. In the same fashion the remaining modes are processed. The electric and magnetic components for each mode are adjusted to correspond to the calculated excitation factor and the total fields are computed by summation. The resulting values of the fields as a function of altitude are printed. In addition, the relative Joule heating in watts per unit volume and the components of the Poynting vector are printed under the headings 'q', 'sx', 'sy' and 'sz'. The angles that the Poynting vector makes with respect to the vertical are shown under the headings 'alpha' and 'beta.' Representative plots for these test data are shown in Figures 4 through 8. It should be noted that the user may obtain other parameters (such as described by Pappert and Shockey, 1977) by modifications to the main routine.

```
PROFILE
TEST CASE
 120.00       5.80E 02
 112.00       1.10E 03
 110.00       1.30E 03
 106.00       1.70E 03
 104.00       1.90E 03
 102.00       1.98E 03
 100.00       2.00E 03
  99.00       1.95E 03
   0.00       1.83E-12
 -99.
COLFREQ
 120.00       1.00E 04
 104.00       3.00E 04
   0.00       1.82E 11
 -99.
ID
WAVFLD test data
NAME
 &DATUM
 FREQ=17.8,
 AZIM=87.801,CODIP=6.593,MAGFLD=.5222D-4,
 SIGMA=1.0D-5,EPSR=5.0,
 RANGER=80,90,RANGEI=0,-5,
 &END
THE TOP OF THE PROFILE IS SET TO BE--
  97.11       1.01E+03
AT THE TOP OF THE PROFILE B =   3.519E+01 OMEGA-R =   3.806E+07
THE BOTTOM PROFILE HEIGHT IS =     67.047 AT B(CUTOFF) =     1.000E-04
OMEGA-R EQUALS 2.5E5 AT HT =   87.06
OMEGA-R =  2.503E+05 AT HOFWR =   87.06
     83.696  -0.665     84.804  -0.101
     74.409  -7.662
     74.409  -7.662

    74.409 -7.662 USED      74.409 -7.662 DELETED
R   0.00 F 17.8000 A  87.801 C   6.593 M 0.522E-04 S 1.000E-05 E  5.0 T 87.1 H 5
 MODE      THETA      ATTEN   VOVERC   WAIT MAG  WAIT ANG        THETAP
   1  84.804  -0.101   0.523  0.99624   -64.578    2.686     89.892  -4.915
   2  83.696  -0.665   4.164  0.99812   -23.736    2.850     88.836  -3.622
   3  74.409  -7.662 117.736  1.02091    16.911   -1.104     75.698  -8.396

QUIT
***THE CALCULATIONS ARE COMPLETE***
FORTRAN STOP
```

Figure 1. Sample output from MODEFNDR. The data obtained in this case are used in the sample run for WAVFLD.

```
PROFILE
TEST CASE
 120.00       5.80E 02
 112.00       1.10E 03
 110.00       1.30E 03
 106.00       1.70E 03
 104.00       1.90E 03
 102.00       1.98E 03
 100.00       2.00E 03
  99.00       1.95E 03
   0.00       1.83E-12
 -99.
COLFREQ
 120.00       1.00E 04
 104.00       3.00E 04
   0.00       1.82E 11
 -99.
NAME
 &DATUM
 TOPHT=120.0,LWSTHT=0.0,
 ITR=1,
 &END
DATA
WAVFLD test data
R  0.000 F 17.8000 A  87.801 C   6.593 M 0.522E-04 S 1.000E-05 E  5.0 T 87.1
1 89.89229 -4.914532 9.64114224E-06 1.96815890E-05-6.95767994E-06 2.03831610E-06
2 89.89229 -4.914532 5.02810508E-06-1.14897985E-05 1.01010334E+00 5.58272935E-03
1 88.83618 -3.622151 6.90992048E-04 2.32309173E-03-2.42370220E-07-1.95802787E-08
2 88.83618 -3.622151-1.51578261E-05 1.88085523E-05 1.01016688E+00 5.75073995E-03
1 75.69807 -8.396441-2.33791590E-01-1.40563220E-01-5.26763112E-11 4.32070248E-11
2 75.69807 -8.396441-4.27416853E-06 3.35867099E-07 1.01005256E+00 8.58251192E-03

R 40.
```

Figure 2. Sample input to the WAVFLD program.

```
PROFILE
TEST CASE
 120.00     5.80E+02
 112.00     1.10E+03
 110.00     1.30E+03
 106.00     1.70E+03
 104.00     1.90E+03
 102.00     1.98E+03
 100.00     2.00E+03
  99.00     1.95E+03
   0.00     1.83E-12
COLFREQ
 120.00     1.00E+04
 104.00     3.00E+04
   0.00     1.82E+11
NAME
$DATUM
H       =  0.00000000000000000E+00,
ALPHA   =  3.14000000000000000E-04,
PREC    =  3.00000000000000000E-05,
DEBUG   =            0,
NELECT  =            0,
COEFNU  =   1816000000000.0000    , 4*4540000000.000000    ,
EXPNU   = 5*-0.15000000000000000  ,
CHARGE  =  -1.00000000000000000   ,  1.00000000000000000   ,
 -1.00000000000000000   ,  1.00000000000000000   , -1.00000000000000000   ,
MRATIO  =   1.00000000000000000   , 4*58000.00000000000   ,
NPROF   =            0,
BETA    =  0.00000000000000000E+00,
HPRIME  =  0.00000000000000000E+00,
SCLHTS  =   5.00000000000000000   ,
TOPHT   =   120.0000000000000     ,
LWSTHT  =  0.00000000000000000E+00,
ITR     =            1,
MAXITR  =           10,
DTHETA  =  5.00000000000000000E-02,  1.00000000000000000E-02,
ILB     =  5.00000000000000000E-02,  5.00000000000000000E-03,
NPRINT  =            1,
SAVPLT  = T
$END
DATA
mode    real      imag      atten   v/c         wait's exc     real'     imag'
  1   89.89229  -4.91453    0.523  0.99633   -64.260  2.686  89.89229  -4.91453
 188 integration steps used in wavfld
modal eqn value=   -3.37864E-01 -2.35654E-01
modal eqn value=   -2.98840E-01  5.59053E-02
new theta=    89.900    -4.967
 188 integration steps used in wavfld
modal eqn value=   -2.50051E-02 -3.20914E-01
modal eqn value=    2.80062E-02  1.31133E-02
new theta=    89.897    -4.963
 188 integration steps used in wavfld
modal eqn value=    7.89829E-04 -1.78629E-03
mode    real      imag      atten   v/c         wait's exc     real'     imag'
  2   88.83618  -3.62215    4.164  0.99821   -23.418  2.850  88.83618  -3.62215
```

Figure 3. Printed output from WAVFLD program.

```
 188 integration steps used in wavfld
modal eqn value=    2.14061E-01 -9.11512E-02
modal eqn value=    1.00186E-01 -1.27949E-01
new theta=    88.872    -3.681
 188 integration steps used in wavfld
modal eqn value=    1.03976E-01  3.90162E-02
modal eqn value=   -7.03339E-03 -1.19096E-02
new theta=    88.868    -3.685
 188 integration steps used in wavfld
modal eqn value=   -4.81178E-04 -2.35637E-04
mode    real       imag       atten   v/c        wait's exc     real'     imag'
  3   75.69807  -8.39644  117.727  1.02100    17.229 -1.104  75.69807  -8.39644
 188 integration steps used in wavfld
modal eqn value=    1.07031E+02  5.21118E+01
modal eqn value=    1.80293E+02  3.14973E+01
new theta=    75.600    -8.470
 188 integration steps used in wavfld
modal eqn value=   -8.10557E+01  2.18985E+01
modal eqn value=   -3.53444E+00 -9.17321E-01
new theta=    75.602    -8.469
 188 integration steps used in wavfld
modal eqn value=   -4.59039E-02  1.72921E-02

WAVFLD test data
r  0.000 f 17.8000 a  87.801 c   6.593 m 0.522 s 1.000E-05 e  5.0 h  0.0
                                                              mag(y) 8.209E+01 modes 3
total Field strengths computed by WAVFLD
```

| ht | | mag — x — ang | | mag — y — ang | | mag — z — ang | | q | sx | sy | sz | alpha | beta |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 120.0 | e | 2.068E-03 | 0.483 | 1.556E-03 | 2.002 | 1.844E-04 | 1.832 | 3.531E-07 | 2.294E-06 | -7.562E-07 | 1.043E-05 | 77.597 | 94.146 |
| | h | 2.484E-03 | -1.145 | 3.177E-03 | 0.441 | 1.543E-03 | 1.958 | | | | | | |
| 118.8 | e | 2.032E-03 | 1.183 | 1.562E-03 | 2.717 | 1.848E-04 | 2.559 | 3.938E-07 | 2.312E-06 | -7.113E-07 | 1.035E-05 | 77.410 | 93.931 |
| | h | 2.504E-03 | -0.421 | 3.168E-03 | 1.169 | 1.549E-03 | 2.673 | | | | | | |
| 117.6 | e | 1.949E-03 | 1.909 | 1.540E-03 | -2.834 | 1.821E-04 | -2.985 | 4.322E-07 | 2.235E-06 | -6.876E-07 | 1.027E-05 | 77.726 | 93.830 |
| | h | 2.587E-03 | 0.339 | 3.227E-03 | 1.923 | 1.527E-03 | -2.879 | | | | | | |
| 116.4 | e | 1.860E-03 | 2.688 | 1.505E-03 | -2.056 | 1.773E-04 | -2.201 | 4.694E-07 | 2.146E-06 | -6.837E-07 | 1.020E-05 | 78.118 | 93.835 |
| | h | 2.697E-03 | 1.104 | 3.301E-03 | 2.682 | 1.493E-03 | -2.101 | | | | | | |
| 115.2 | e | 1.820E-03 | -2.780 | 1.503E-03 | -1.243 | 1.762E-04 | -1.378 | 5.238E-07 | 2.163E-06 | -6.909E-07 | 1.013E-05 | 77.943 | 93.903 |
| | h | 2.748E-03 | 1.889 | 3.296E-03 | -2.819 | 1.491E-03 | -1.287 | | | | | | |
| 114.0 | e | 1.793E-03 | -1.960 | 1.508E-03 | -0.423 | 1.769E-04 | -0.549 | 5.948E-07 | 2.171E-06 | -6.964E-07 | 1.005E-05 | 77.814 | 93.962 |
| | h | 2.777E-03 | 2.730 | 3.273E-03 | -1.979 | 1.496E-03 | -0.468 | | | | | | |
| 112.8 | e | 1.718E-03 | -1.111 | 1.469E-03 | 0.424 | 1.725E-04 | 0.302 | 6.544E-07 | 2.041E-06 | -6.925E-07 | 9.987E-06 | 78.448 | 93.967 |
| | h | 2.886E-03 | -2.675 | 3.348E-03 | -1.101 | 1.457E-03 | 0.380 | | | | | | |
| 111.6 | e | 1.648E-03 | -0.196 | 1.427E-03 | 1.338 | 1.669E-04 | 1.219 | 7.173E-07 | 1.941E-06 | -6.871E-07 | 9.926E-06 | 78.935 | 93.960 |
| | h | 2.998E-03 | -1.792 | 3.429E-03 | -0.218 | 1.415E-03 | 1.293 | | | | | | |
| 110.4 | e | 1.631E-03 | 0.748 | 1.429E-03 | 2.283 | 1.669E-04 | 2.173 | 8.259E-07 | 1.963E-06 | -6.868E-07 | 9.869E-06 | 78.751 | 93.981 |
| | h | 3.017E-03 | -0.862 | 3.409E-03 | 0.711 | 1.418E-03 | 2.239 | | | | | | |
| 109.2 | e | 1.585E-03 | 1.706 | 1.407E-03 | -3.043 | 1.645E-04 | 3.133 | 9.242E-07 | 1.879E-06 | -6.828E-07 | 9.815E-06 | 79.162 | 93.979 |
| | h | 3.088E-03 | 0.135 | 3.454E-03 | 1.707 | 1.396E-03 | -3.088 | | | | | | |
| 108.0 | e | 1.520E-03 | 2.730 | 1.360E-03 | -2.021 | 1.587E-04 | -2.127 | 1.003E-06 | 1.765E-06 | -6.757E-07 | 9.768E-06 | 79.759 | 93.957 |
| | h | 3.209E-03 | 1.136 | 3.555E-03 | 2.708 | 1.349E-03 | -2.066 | | | | | | |
| 106.8 | e | 1.513E-03 | -2.495 | 1.364E-03 | -0.961 | 1.587E-04 | -1.061 | 1.153E-06 | 1.790E-06 | -6.736E-07 | 9.725E-06 | 79.569 | 93.962 |
| | h | 3.215E-03 | 2.174 | 3.534E-03 | -2.537 | 1.353E-03 | -1.005 | | | | | | |
| 105.6 | e | 1.475E-03 | -1.430 | 1.343E-03 | 0.104 | 1.565E-04 | 0.006 | 1.288E-06 | 1.712E-06 | -6.683E-07 | 9.686E-06 | 79.979 | 93.947 |
| | h | 3.280E-03 | -3.001 | 3.582E-03 | -1.429 | 1.332E-03 | 0.060 | | | | | | |
| 104.4 | e | 1.423E-03 | -0.291 | 1.302E-03 | 1.240 | 1.513E-04 | 1.143 | 1.393E-06 | 1.622E-06 | -6.640E-07 | 9.654E-06 | 80.464 | 93.934 |

Figure 3. Printed output from WAVFLD program (contd).

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | 3.390E-03 | -1.896 | 3.684E-03 | -0.324 | 1.291E-03 | 1.196 | | | | | | |
| 103.2 | e | 1.435E-03 | 0.865 | 1.316E-03 | 2.397 | 1.526E-04 | 2.303 | 1.690E-06 | 1.668E-06 | -6.656E-07 | 9.627E-06 | 80.169 | 93.955 |
| | h | 3.357E-03 | -0.752 | 3.635E-03 | 0.819 | 1.306E-03 | 2.353 | | | | | | |
| 102.0 | e | 1.413E-03 | 2.014 | 1.300E-03 | -2.737 | 1.505E-04 | -2.833 | 2.020E-06 | 1.608E-06 | -6.597E-07 | 9.609E-06 | 80.499 | 93.927 |
| | h | 3.402E-03 | 0.428 | 3.673E-03 | 1.999 | 1.290E-03 | -2.782 | | | | | | |
| 100.8 | e | 1.398E-03 | -3.077 | 1.289E-03 | -1.544 | 1.485E-04 | -1.641 | 2.388E-06 | 1.603E-06 | -6.560E-07 | 9.601E-06 | 80.521 | 93.909 |
| | h | 3.438E-03 | 1.579 | 3.702E-03 | -3.129 | 1.280E-03 | -1.589 | | | | | | |
| 99.6 | e | 1.417E-03 | -1.906 | 1.321E-03 | -0.380 | 1.518E-04 | -0.477 | 2.937E-06 | 1.672E-06 | -6.744E-07 | 9.603E-06 | 80.123 | 94.018 |
| | h | 3.361E-03 | 2.755 | 3.647E-03 | -1.944 | 1.311E-03 | -0.425 | | | | | | |
| 98.4 | e | 1.422E-03 | -0.730 | 1.316E-03 | 0.758 | 1.496E-04 | 0.646 | 2.946E-06 | 1.659E-06 | -7.310E-07 | 9.614E-06 | 80.207 | 94.348 |
| | h | 3.315E-03 | -2.411 | 3.711E-03 | -0.823 | 1.306E-03 | 0.713 | | | | | | |
| 97.2 | e | 1.656E-03 | 0.323 | 1.470E-03 | 1.773 | 1.633E-04 | 1.648 | 3.177E-06 | 2.149E-06 | -8.688E-07 | 9.616E-06 | 77.401 | 95.163 |
| | h | 2.889E-03 | -1.544 | 3.392E-03 | 0.066 | 1.459E-03 | 1.728 | | | | | | |
| 96.0 | e | 1.923E-03 | 1.108 | 1.658E-03 | 2.509 | 1.823E-04 | 2.355 | 3.548E-06 | 2.659E-06 | -1.104E-06 | 9.605E-06 | 74.527 | 96.555 |
| | h | 2.368E-03 | -0.746 | 3.024E-03 | 0.911 | 1.647E-03 | 2.464 | | | | | | |
| 94.8 | e | 2.049E-03 | 1.787 | 1.704E-03 | 3.091 | 1.836E-04 | 2.859 | 3.894E-06 | 2.683E-06 | -1.435E-06 | 9.591E-06 | 74.373 | 98.496 |
| | h | 2.071E-03 | -0.036 | 2.981E-03 | 1.665 | 1.694E-03 | 3.046 | | | | | | |
| 93.6 | e | 2.173E-03 | 2.445 | 1.668E-03 | -2.671 | 1.710E-04 | -3.058 | 4.873E-06 | 2.464E-06 | -1.853E-06 | 9.596E-06 | 75.598 | 100.932 |
| | h | 1.870E-03 | 0.523 | 3.027E-03 | 2.273 | 1.659E-03 | -2.716 | | | | | | |
| 92.4 | e | 2.420E-03 | 3.047 | 1.640E-03 | -2.193 | 1.584E-04 | -2.864 | 6.890E-06 | 2.294E-06 | -2.354E-06 | 9.643E-06 | 76.620 | 103.716 |
| | h | 1.651E-03 | 0.959 | 2.956E-03 | 2.800 | 1.633E-03 | -2.240 | | | | | | |
| 91.2 | e | 2.735E-03 | -2.724 | 1.653E-03 | -1.775 | 1.760E-04 | -2.887 | 1.033E-05 | 2.227E-06 | -2.924E-06 | 9.757E-06 | 77.141 | 106.685 |
| | h | 1.418E-03 | 1.319 | 2.788E-03 | -2.959 | 1.646E-03 | -1.825 | | | | | | |
| 90.0 | e | 3.004E-03 | -2.278 | 1.692E-03 | -1.425 | 2.826E-04 | -2.943 | 1.703E-05 | 2.201E-06 | -3.571E-06 | 9.987E-06 | 77.570 | 109.676 |
| | h | 1.200E-03 | 1.632 | 2.669E-03 | -2.397 | 1.684E-03 | -1.478 | | | | | | |
| 88.8 | e | 3.194E-03 | -1.856 | 1.735E-03 | -1.138 | 5.600E-04 | -2.864 | 3.280E-05 | 2.219E-06 | -4.296E-06 | 1.048E-05 | 78.038 | 112.300 |
| | h | 1.015E-03 | 1.921 | 2.733E-03 | -1.819 | 1.724E-03 | -1.193 | | | | | | |
| 87.6 | e | 3.402E-03 | -1.433 | 1.763E-03 | -0.898 | 1.140E-03 | -2.744 | 6.958E-05 | 2.745E-06 | -5.049E-06 | 1.158E-05 | 76.667 | 113.551 |
| | h | 8.706E-04 | 2.203 | 2.994E-03 | -1.270 | 1.748E-03 | -0.955 | | | | | | |
| 86.4 | e | 3.808E-03 | -1.035 | 1.764E-03 | -0.691 | 2.163E-03 | -2.675 | 1.353E-04 | 5.564E-06 | -5.648E-06 | 1.393E-05 | 68.225 | 112.072 |
| | h | 7.739E-04 | 2.488 | 3.427E-03 | -0.762 | 1.745E-03 | -0.749 | | | | | | |
| 85.2 | e | 4.438E-03 | -0.734 | 1.739E-03 | -0.502 | 3.549E-03 | -2.650 | 2.003E-04 | 1.340E-05 | -5.866E-06 | 1.783E-05 | 53.074 | 108.215 |
| | h | 7.207E-04 | 2.755 | 4.136E-03 | -0.290 | 1.716E-03 | -0.560 | | | | | | |
| 84.0 | e | 5.050E-03 | -0.543 | 1.694E-03 | -0.320 | 5.099E-03 | -2.603 | 2.272E-04 | 2.738E-05 | -5.607E-06 | 2.248E-05 | 39.389 | 104.003 |
| | h | 6.881E-04 | 2.987 | 5.306E-03 | 0.107 | 1.667E-03 | -0.379 | | | | | | |
| 82.8 | e | 5.449E-03 | -0.429 | 1.640E-03 | -0.142 | 6.837E-03 | -2.524 | 2.240E-04 | 4.909E-05 | -4.757E-06 | 2.673E-05 | 28.563 | 100.093 |
| | h | 6.583E-04 | -3.095 | 6.960E-03 | 0.399 | 1.610E-03 | -0.202 | | | | | | |
| 81.6 | e | 5.605E-03 | -0.365 | 1.585E-03 | 0.033 | 8.791E-03 | -2.443 | 2.030E-04 | 8.085E-05 | -3.295E-06 | 2.962E-05 | 20.124 | 96.346 |
| | h | 6.263E-04 | -2.916 | 8.961E-03 | 0.599 | 1.551E-03 | -0.026 | | | | | | |
| 80.4 | e | 5.554E-03 | -0.341 | 1.534E-03 | 0.205 | 1.090E-02 | -2.374 | 1.711E-04 | 1.238E-04 | -1.353E-06 | 3.042E-05 | 13.807 | 92.547 |
| | h | 5.911E-04 | -2.752 | 1.115E-02 | 0.733 | 1.497E-03 | 0.147 | | | | | | |
| 79.2 | e | 5.350E-03 | -0.353 | 1.489E-03 | 0.371 | 1.308E-02 | -2.321 | 1.351E-04 | 1.776E-04 | 8.689E-07 | 2.852E-05 | 9.123 | 88.255 |
| | h | 5.528E-04 | -2.600 | 1.342E-02 | 0.821 | 1.450E-03 | 0.316 | | | | | | |
| 78.0 | e | 5.049E-03 | -0.401 | 1.450E-03 | 0.532 | 1.525E-02 | -2.284 | 1.007E-04 | 2.409E-04 | 3.162E-06 | 2.355E-05 | 5.583 | 82.351 |
| | h | 5.122E-04 | -2.455 | 1.566E-02 | 0.877 | 1.410E-03 | 0.479 | | | | | | |
| 76.8 | e | 4.705E-03 | -0.487 | 1.417E-03 | 0.683 | 1.737E-02 | -2.263 | 7.163E-05 | 3.116E-04 | 5.332E-06 | 1.532E-05 | 2.815 | 70.813 |
| | h | 4.702E-04 | -2.313 | 1.784E-02 | 0.908 | 1.377E-03 | 0.633 | | | | | | |
| 75.6 | e | 4.375E-03 | -0.613 | 1.388E-03 | 0.825 | 1.939E-02 | -2.256 | 4.894E-05 | 3.875E-04 | 7.210E-06 | 3.848E-06 | 0.569 | 28.090 |
| | h | 4.282E-04 | -2.170 | 1.990E-02 | 0.920 | 1.349E-03 | 0.777 | | | | | | |
| 74.4 | e | 4.116E-03 | -0.780 | 1.361E-03 | 0.956 | 2.129E-02 | -2.262 | 3.236E-05 | 4.664E-04 | 8.659E-06 | -1.076E-05 | -1.321 | -51.168 |
| | h | 3.873E-04 | -2.023 | 2.184E-02 | 0.916 | 1.323E-03 | 0.910 | | | | | | |
| 73.2 | e | 3.984E-03 | -0.982 | 1.332E-03 | 1.077 | 2.306E-02 | -2.280 | 2.083E-05 | 5.466E-04 | 9.579E-06 | -2.828E-05 | -2.962 | -71.289 |
| | h | 3.485E-04 | -1.868 | 2.364E-02 | 0.899 | 1.297E-03 | 1.032 | | | | | | |
| 72.0 | e | 4.019E-03 | -1.202 | 1.299E-03 | 1.186 | 2.471E-02 | -2.310 | 1.313E-05 | 6.269E-04 | 9.910E-06 | -4.845E-05 | -4.420 | -78.440 |
| | h | 3.129E-04 | -1.702 | 2.532E-02 | 0.870 | 1.267E-03 | 1.143 | | | | | | |

Figure 3. Printed output from WAVFLD program (contd).

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 70.8 | e | 4.230E-03 | -1.419 | 1.261E-03 | 1.286 | 2.625E-02 | -2.349 | 8.136E-06 | 7.066E-04 | 9.637E-06 | -7.095E-05 | -5.733 | -82.265 |
| | h | 2.815E-04 | -1.524 | 2.687E-02 | 0.830 | 1.232E-03 | 1.243 | | | | | | |
| 69.6 | e | 4.597E-03 | -1.616 | 1.217E-03 | 1.375 | 2.770E-02 | -2.398 | 4.978E-06 | 7.860E-04 | 8.785E-06 | -9.544E-05 | -6.924 | -84.741 |
| | h | 2.548E-04 | -1.331 | 2.834E-02 | 0.780 | 1.191E-03 | 1.333 | | | | | | |
| 68.4 | e | 5.080E-03 | -1.788 | 1.165E-03 | 1.456 | 2.908E-02 | -2.456 | 3.019E-06 | 8.656E-04 | 7.421E-06 | -1.216E-04 | -7.997 | -86.508 |
| | h | 2.335E-04 | -1.126 | 2.974E-02 | 0.721 | 1.143E-03 | 1.414 | | | | | | |
| 67.2 | e | 5.640E-03 | -1.935 | 1.106E-03 | 1.528 | 3.042E-02 | -2.521 | 1.821E-06 | 9.466E-04 | 5.648E-06 | -1.491E-04 | -8.952 | -87.831 |
| | h | 2.178E-04 | -0.912 | 3.110E-02 | 0.654 | 1.088E-03 | 1.485 | | | | | | |
| 66.0 | e | 6.240E-03 | -2.063 | 1.039E-03 | 1.591 | 3.175E-02 | -2.593 | 1.094E-06 | 1.031E-03 | 3.597E-06 | -1.777E-04 | -9.784 | -88.841 |
| | h | 2.073E-04 | -0.696 | 3.245E-02 | 0.580 | 1.026E-03 | 1.547 | | | | | | |
| 64.8 | e | 6.856E-03 | -2.177 | 9.658E-04 | 1.645 | 3.309E-02 | -2.672 | 6.569E-07 | 1.120E-03 | 1.420E-06 | -2.073E-04 | -10.485 | -89.607 |
| | h | 2.014E-04 | -0.484 | 3.383E-02 | 0.500 | 9.563E-04 | 1.600 | | | | | | |
| 63.6 | e | 7.466E-03 | -2.282 | 8.864E-04 | 1.689 | 3.448E-02 | -2.755 | 3.941E-07 | 1.216E-03 | -7.195E-07 | -2.376E-04 | -11.055 | -90.174 |
| | h | 1.991E-04 | -0.284 | 3.526E-02 | 0.415 | 8.810E-04 | 1.643 | | | | | | |
| 62.4 | e | 8.058E-03 | -2.381 | 8.021E-04 | 1.723 | 3.592E-02 | -2.843 | 2.365E-07 | 1.321E-03 | -2.661E-06 | -2.687E-04 | -11.496 | -90.567 |
| | h | 1.992E-04 | -0.098 | 3.677E-02 | 0.326 | 8.008E-04 | 1.675 | | | | | | |
| 61.2 | e | 8.622E-03 | -2.478 | 7.141E-04 | 1.743 | 3.745E-02 | -2.933 | 1.419E-07 | 1.437E-03 | -4.255E-06 | -3.006E-04 | -11.819 | -90.811 |
| | h | 2.007E-04 | 0.072 | 3.837E-02 | 0.234 | 7.169E-04 | 1.693 | | | | | | |
| 60.0 | e | 9.154E-03 | -2.574 | 6.239E-04 | 1.747 | 3.905E-02 | -3.026 | 8.512E-08 | 1.564E-03 | -5.375E-06 | -3.336E-04 | -12.041 | -90.923 |
| | h | 2.026E-04 | 0.226 | 4.005E-02 | 0.140 | 6.310E-04 | 1.693 | | | | | | |
| 58.8 | e | 9.654E-03 | -2.672 | 5.337E-04 | 1.726 | 4.073E-02 | -3.121 | 5.103E-08 | 1.703E-03 | -5.923E-06 | -3.678E-04 | -12.185 | -90.922 |
| | h | 2.042E-04 | 0.366 | 4.183E-02 | 0.044 | 5.451E-04 | 1.670 | | | | | | |
| 57.6 | e | 1.013E-02 | -2.772 | 4.463E-04 | 1.670 | 4.247E-02 | 3.067 | 3.055E-08 | 1.855E-03 | -5.841E-06 | -4.037E-04 | -12.276 | -90.829 |
| | h | 2.051E-04 | 0.494 | 4.368E-02 | -0.052 | 4.621E-04 | 1.614 | | | | | | |
| 56.4 | e | 1.057E-02 | -2.876 | 3.660E-04 | 1.560 | 4.427E-02 | 2.971 | 1.885E-21 | 2.018E-03 | -5.115E-06 | -4.415E-04 | -12.340 | -90.664 |
| | h | 2.049E-04 | 0.612 | 4.560E-02 | -0.148 | 3.863E-04 | 1.507 | | | | | | |
| 55.2 | e | 1.101E-02 | -2.985 | 3.004E-04 | 1.368 | 4.610E-02 | 2.875 | 0.000E+00 | 2.192E-03 | -3.775E-06 | -4.819E-04 | -12.400 | -90.449 |
| | h | 2.034E-04 | 0.721 | 4.755E-02 | -0.245 | 3.244E-04 | 1.330 | | | | | | |
| 54.0 | e | 1.145E-02 | -3.098 | 2.607E-04 | 1.076 | 4.794E-02 | 2.777 | 2.301E-25 | 2.373E-03 | -1.895E-06 | -5.251E-04 | -12.477 | -90.207 |
| | h | 2.006E-04 | 0.825 | 4.951E-02 | -0.343 | 2.860E-04 | 1.072 | | | | | | |
| 52.8 | e | 1.190E-02 | 3.067 | 2.580E-04 | 0.732 | 4.976E-02 | 2.679 | 0.000E+00 | 2.560E-03 | 4.105E-07 | -5.718E-04 | -12.589 | -89.959 |
| | h | 1.964E-04 | 0.923 | 5.146E-02 | -0.440 | 2.800E-04 | 0.767 | | | | | | |
| 51.6 | e | 1.238E-02 | 2.945 | 2.908E-04 | 0.438 | 5.154E-02 | 2.580 | 1.180E-22 | 2.751E-03 | 2.991E-06 | -6.224E-04 | -12.750 | -89.725 |
| | h | 1.908E-04 | 1.017 | 5.338E-02 | -0.539 | 3.063E-04 | 0.494 | | | | | | |
| 50.4 | e | 1.290E-02 | 2.818 | 3.467E-04 | 0.240 | 5.327E-02 | 2.480 | -7.539E-21 | 2.942E-03 | 5.672E-06 | -6.775E-04 | -12.968 | -89.520 |
| | h | 1.840E-04 | 1.108 | 5.524E-02 | -0.639 | 3.554E-04 | 0.296 | | | | | | |
| 49.2 | e | 1.349E-02 | 2.689 | 4.134E-04 | 0.121 | 5.493E-02 | 2.377 | 0.000E+00 | 3.132E-03 | 8.260E-06 | -7.375E-04 | -13.252 | -89.358 |
| | h | 1.761E-04 | 1.198 | 5.702E-02 | -0.741 | 4.167E-04 | 0.169 | | | | | | |
| 48.0 | e | 1.416E-02 | 2.558 | 4.838E-04 | 0.052 | 5.651E-02 | 2.272 | -7.539E-21 | 3.318E-03 | 1.056E-05 | -8.029E-04 | -13.603 | -89.247 |
| | h | 1.672E-04 | 1.287 | 5.873E-02 | -0.846 | 4.830E-04 | 0.092 | | | | | | |
| 46.8 | e | 1.491E-02 | 2.426 | 5.538E-04 | 0.014 | 5.803E-02 | 2.164 | 0.000E+00 | 3.502E-03 | 1.238E-05 | -8.745E-04 | -14.021 | -89.189 |
| | h | 1.575E-04 | 1.376 | 6.036E-02 | -0.953 | 5.500E-04 | 0.047 | | | | | | |
| 45.6 | e | 1.575E-02 | 2.295 | 6.211E-04 | -0.004 | 5.948E-02 | 2.052 | 4.712E-22 | 3.683E-03 | 1.354E-05 | -9.526E-04 | -14.503 | -89.185 |
| | h | 1.470E-04 | 1.467 | 6.193E-02 | -1.064 | 6.150E-04 | 0.023 | | | | | | |
| 44.4 | e | 1.670E-02 | 2.164 | 6.844E-04 | -0.009 | 6.090E-02 | 1.936 | 0.000E+00 | 3.864E-03 | 1.391E-05 | -1.038E-03 | -15.039 | -89.232 |
| | h | 1.361E-04 | 1.561 | 6.345E-02 | -1.179 | 6.766E-04 | 0.013 | | | | | | |
| 43.2 | e | 1.774E-02 | 2.036 | 7.428E-04 | -0.005 | 6.233E-02 | 1.816 | -4.712E-22 | 4.049E-03 | 1.339E-05 | -1.132E-03 | -15.617 | -89.322 |
| | h | 1.250E-04 | 1.659 | 6.498E-02 | -1.298 | 7.337E-04 | 0.012 | | | | | | |
| 42.0 | e | 1.889E-02 | 1.909 | 7.956E-04 | 0.004 | 6.381E-02 | 1.690 | 0.000E+00 | 4.245E-03 | 1.190E-05 | -1.235E-03 | -16.216 | -89.448 |
| | h | 1.137E-04 | 1.763 | 6.655E-02 | -1.422 | 7.857E-04 | 0.019 | | | | | | |
| 40.8 | e | 2.013E-02 | 1.785 | 8.426E-04 | 0.018 | 6.540E-02 | 1.560 | 4.712E-22 | 4.461E-03 | 9.440E-06 | -1.348E-03 | -16.812 | -89.599 |
| | h | 1.025E-04 | 1.876 | 6.823E-02 | -1.551 | 8.321E-04 | 0.030 | | | | | | |
| 39.6 | e | 2.147E-02 | 1.663 | 8.836E-04 | 0.035 | 6.719E-02 | 1.425 | -3.769E-21 | 4.708E-03 | 6.055E-06 | -1.473E-03 | -17.375 | -89.764 |
| | h | 9.162E-05 | 2.002 | 7.009E-02 | -1.685 | 8.727E-04 | 0.044 | | | | | | |
| 38.4 | e | 2.289E-02 | 1.542 | 9.183E-04 | 0.054 | 6.925E-02 | 1.285 | 0.000E+00 | 5.000E-03 | 1.837E-06 | -1.612E-03 | -17.873 | -89.935 |

Figure 3. Printed output from WAVFLD program (contd).

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | h | 8.137E-05 | 2.143 | 7.223E-02 | -1.823 | 9.072E-04 | 0.061 | | | | | | |
| 37.2 | e | 2.440E-02 | 1.424 | 9.468E-04 | 0.074 | 7.168E-02 | 1.142 | 0.000E+00 | 5.353E-03 | -3.072E-06 | -1.768E-03 | -18.275 | -90.100 |
| | h | 7.202E-05 | 2.306 | 7.472E-02 | -1.964 | 9.358E-04 | 0.079 | | | | | | |
| 36.0 | e | 2.599E-02 | 1.307 | 9.692E-04 | 0.095 | 7.455E-02 | 0.996 | 0.000E+00 | 5.787E-03 | -8.488E-06 | -1.942E-03 | -18.556 | -90.250 |
| | h | 6.393E-05 | 2.494 | 7.766E-02 | -2.109 | 9.584E-04 | 0.099 | | | | | | |
| 34.8 | e | 2.765E-02 | 1.192 | 9.856E-04 | 0.117 | 7.796E-02 | 0.848 | -9.423E-22 | 6.322E-03 | -1.419E-05 | -2.140E-03 | -18.699 | -90.380 |
| | h | 5.749E-05 | 2.710 | 8.114E-02 | -2.256 | 9.750E-04 | 0.120 | | | | | | |
| 33.6 | e | 2.940E-02 | 1.077 | 9.961E-04 | 0.140 | 8.198E-02 | 0.700 | 0.000E+00 | 6.982E-03 | -1.994E-05 | -2.363E-03 | -18.702 | -90.483 |
| | h | 5.310E-05 | 2.952 | 8.522E-02 | -2.403 | 9.859E-04 | 0.141 | | | | | | |
| 32.4 | e | 3.122E-02 | 0.962 | 1.001E-03 | 0.163 | 8.667E-02 | 0.552 | -1.319E-20 | 7.793E-03 | -2.548E-05 | -2.619E-03 | -18.574 | -90.558 |
| | h | 5.098E-05 | -3.075 | 8.998E-02 | -2.550 | 9.913E-04 | 0.163 | | | | | | |
| 31.2 | e | 3.313E-02 | 0.848 | 1.001E-03 | 0.185 | 9.207E-02 | 0.406 | 7.538E-21 | 8.782E-03 | -3.056E-05 | -2.910E-03 | -18.336 | -90.602 |
| | h | 5.110E-05 | -2.822 | 9.545E-02 | -2.695 | 9.914E-04 | 0.184 | | | | | | |
| 30.0 | e | 3.512E-02 | 0.734 | 9.950E-04 | 0.208 | 9.821E-02 | 0.262 | -7.538E-21 | 9.980E-03 | -3.493E-05 | -3.246E-03 | -18.015 | -90.617 |
| | h | 5.309E-05 | -2.589 | 1.017E-01 | -2.838 | 9.864E-04 | 0.206 | | | | | | |
| 28.8 | e | 3.721E-02 | 0.619 | 9.846E-04 | 0.230 | 1.051E-01 | 0.122 | -1.886E-21 | 1.142E-02 | -3.837E-05 | -3.631E-03 | -17.641 | -90.605 |
| | h | 5.645E-05 | -2.386 | 1.087E-01 | -2.979 | 9.766E-04 | 0.228 | | | | | | |
| 27.6 | e | 3.940E-02 | 0.504 | 9.698E-04 | 0.252 | 1.128E-01 | -0.016 | -9.202E-25 | 1.313E-02 | -4.070E-05 | -4.075E-03 | -17.241 | -90.572 |
| | h | 6.065E-05 | -2.212 | 1.165E-01 | -3.116 | 9.624E-04 | 0.249 | | | | | | |
| 26.4 | e | 4.171E-02 | 0.388 | 9.507E-04 | 0.274 | 1.212E-01 | -0.150 | 0.000E+00 | 1.515E-02 | -4.177E-05 | -4.586E-03 | -16.840 | -90.522 |
| | h | 6.528E-05 | -2.065 | 1.251E-01 | 3.033 | 9.440E-04 | 0.270 | | | | | | |
| 25.2 | e | 4.414E-02 | 0.272 | 9.278E-04 | 0.295 | 1.304E-01 | -0.280 | 1.885E-21 | 1.752E-02 | -4.148E-05 | -5.175E-03 | -16.455 | -90.459 |
| | h | 7.003E-05 | -1.939 | 1.344E-01 | 2.903 | 9.217E-04 | 0.290 | | | | | | |
| 24.0 | e | 4.673E-02 | 0.156 | 9.014E-04 | 0.315 | 1.404E-01 | -0.408 | -1.508E-20 | 2.028E-02 | -3.981E-05 | -5.854E-03 | -16.099 | -90.390 |
| | h | 7.470E-05 | -1.830 | 1.446E-01 | 2.775 | 8.959E-04 | 0.310 | | | | | | |
| 22.8 | e | 4.948E-02 | 0.039 | 8.718E-04 | 0.335 | 1.511E-01 | -0.532 | -3.039E-20 | 2.348E-02 | -3.678E-05 | -6.635E-03 | -15.781 | -90.318 |
| | h | 7.915E-05 | -1.734 | 1.555E-01 | 2.650 | 8.669E-04 | 0.330 | | | | | | |
| 21.6 | e | 5.241E-02 | -0.079 | 8.393E-04 | 0.354 | 1.626E-01 | -0.655 | -4.601E-25 | 2.715E-02 | -3.245E-05 | -7.532E-03 | -15.503 | -90.247 |
| | h | 8.332E-05 | -1.649 | 1.671E-01 | 2.527 | 8.350E-04 | 0.348 | | | | | | |
| 20.4 | e | 5.554E-02 | -0.197 | 8.042E-04 | 0.372 | 1.748E-01 | -0.775 | 0.000E+00 | 3.137E-02 | -2.697E-05 | -8.562E-03 | -15.267 | -90.180 |
| | h | 8.715E-05 | -1.573 | 1.796E-01 | 2.407 | 8.004E-04 | 0.366 | | | | | | |
| 19.2 | e | 5.889E-02 | -0.315 | 7.667E-04 | 0.390 | 1.878E-01 | -0.894 | 3.015E-20 | 3.618E-02 | -2.052E-05 | -9.743E-03 | -15.072 | -90.121 |
| | h | 9.062E-05 | -1.504 | 1.928E-01 | 2.288 | 7.635E-04 | 0.383 | | | | | | |
| 18.0 | e | 6.248E-02 | -0.433 | 7.273E-04 | 0.406 | 2.016E-01 | -1.011 | 2.639E-20 | 4.165E-02 | -1.334E-05 | -1.109E-02 | -14.913 | -90.069 |
| | h | 9.373E-05 | -1.440 | 2.068E-01 | 2.170 | 7.246E-04 | 0.399 | | | | | | |
| 16.8 | e | 6.634E-02 | -0.551 | 6.861E-04 | 0.421 | 2.161E-01 | -1.127 | 3.769E-21 | 4.787E-02 | -5.689E-06 | -1.264E-02 | -14.788 | -90.026 |
| | h | 9.649E-05 | -1.382 | 2.217E-01 | 2.054 | 6.838E-04 | 0.413 | | | | | | |
| 15.6 | e | 7.048E-02 | -0.669 | 6.433E-04 | 0.435 | 2.315E-01 | -1.242 | 0.000E+00 | 5.491E-02 | 2.128E-06 | -1.440E-02 | -14.693 | -89.992 |
| | h | 9.891E-05 | -1.329 | 2.374E-01 | 1.939 | 6.414E-04 | 0.427 | | | | | | |
| 14.4 | e | 7.493E-02 | -0.786 | 5.992E-04 | 0.447 | 2.478E-01 | -1.356 | -1.508E-20 | 6.289E-02 | 9.796E-06 | -1.641E-02 | -14.623 | -89.966 |
| | h | 1.010E-04 | -1.279 | 2.540E-01 | 1.824 | 5.977E-04 | 0.439 | | | | | | |
| 13.2 | e | 7.971E-02 | -0.904 | 5.540E-04 | 0.458 | 2.650E-01 | -1.470 | 7.539E-21 | 7.191E-02 | 1.699E-05 | -1.870E-02 | -14.574 | -89.948 |
| | h | 1.029E-04 | -1.234 | 2.715E-01 | 1.710 | 5.528E-04 | 0.449 | | | | | | |
| 12.0 | e | 8.484E-02 | -1.021 | 5.078E-04 | 0.467 | 2.833E-01 | -1.584 | 3.769E-21 | 8.211E-02 | 2.340E-05 | -2.130E-02 | -14.543 | -89.937 |
| | h | 1.044E-04 | -1.192 | 2.901E-01 | 1.596 | 5.069E-04 | 0.458 | | | | | | |
| 10.8 | e | 9.034E-02 | -1.137 | 4.609E-04 | 0.474 | 3.026E-01 | -1.698 | 1.150E-25 | 9.364E-02 | 2.870E-05 | -2.426E-02 | -14.524 | -89.932 |
| | h | 1.058E-04 | -1.154 | 3.097E-01 | 1.482 | 4.602E-04 | 0.465 | | | | | | |
| 9.6 | e | 9.625E-02 | -1.254 | 4.134E-04 | 0.479 | 3.230E-01 | -1.811 | 5.751E-26 | 1.067E-01 | 3.261E-05 | -2.762E-02 | -14.516 | -89.932 |
| | h | 1.069E-04 | -1.119 | 3.305E-01 | 1.369 | 4.128E-04 | 0.469 | | | | | | |
| 8.4 | e | 1.026E-01 | -1.369 | 3.653E-04 | 0.480 | 3.447E-01 | -1.924 | 0.000E+00 | 1.215E-01 | 3.486E-05 | -3.145E-02 | -14.514 | -89.936 |
| | h | 1.079E-04 | -1.088 | 3.526E-01 | 1.255 | 3.649E-04 | 0.471 | | | | | | |
| 7.2 | e | 1.094E-01 | -1.484 | 3.168E-04 | 0.478 | 3.678E-01 | -2.038 | 0.000E+00 | 1.382E-01 | 3.524E-05 | -3.579E-02 | -14.517 | -89.944 |
| | h | 1.087E-04 | -1.061 | 3.761E-01 | 1.142 | 3.165E-04 | 0.468 | | | | | | |
| 6.0 | e | 1.167E-01 | -1.599 | 2.681E-04 | 0.470 | 3.923E-01 | -2.151 | 2.356E-22 | 1.572E-01 | 3.356E-05 | -4.073E-02 | -14.521 | -89.953 |
| | h | 1.093E-04 | -1.037 | 4.011E-01 | 1.028 | 2.679E-04 | 0.460 | | | | | | |

Figure 3. Printed output from WAVFLD program (contd).

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4.8 | e | 1.244E-01 | -1.713 | 2.192E-04 | 0.453 | 4.185E-01 | -2.265 | -7.189E-27 | 1.788E-01 | 2.967E-05 | -4.634E-02 | -14.526 | -89.963 |
| | h | 1.099E-04 | -1.018 | 4.276E-01 | 0.915 | 2.191E-04 | 0.443 | | | | | | |
| 3.6 | e | 1.328E-01 | -1.826 | 1.703E-04 | 0.422 | 4.464E-01 | -2.379 | 1.885E-21 | 2.034E-01 | 2.349E-05 | -5.271E-02 | -14.529 | -89.974 |
| | h | 1.103E-04 | -1.002 | 4.560E-01 | 0.801 | 1.702E-04 | 0.412 | | | | | | |
| 2.4 | e | 1.417E-01 | -1.939 | 1.216E-04 | 0.360 | 4.762E-01 | -2.492 | 1.885E-21 | 2.314E-01 | 1.496E-05 | -5.996E-02 | -14.529 | -89.986 |
| | h | 1.107E-04 | -0.990 | 4.862E-01 | 0.688 | 1.215E-04 | 0.350 | | | | | | |
| 1.2 | e | 1.512E-01 | -2.052 | 7.403E-05 | 0.210 | 5.080E-01 | -2.606 | -1.123E-28 | 2.632E-01 | 4.092E-06 | -6.820E-02 | -14.526 | -89.997 |
| | h | 1.110E-04 | -0.983 | 5.185E-01 | 0.574 | 7.400E-05 | 0.199 | | | | | | |
| 0.0 | e | 1.614E-01 | -2.164 | 3.339E-05 | -0.376 | 5.420E-01 | -2.719 | 0.000E+00 | 2.996E-01 | -9.070E-06 | -7.758E-02 | -14.519 | -90.007 |
| | h | 1.113E-04 | -0.979 | 5.531E-01 | 0.460 | 3.337E-05 | -0.387 | | | | | | |

FORTRAN STOP

Figure 3. Printed output from WAVFLD program (contd).

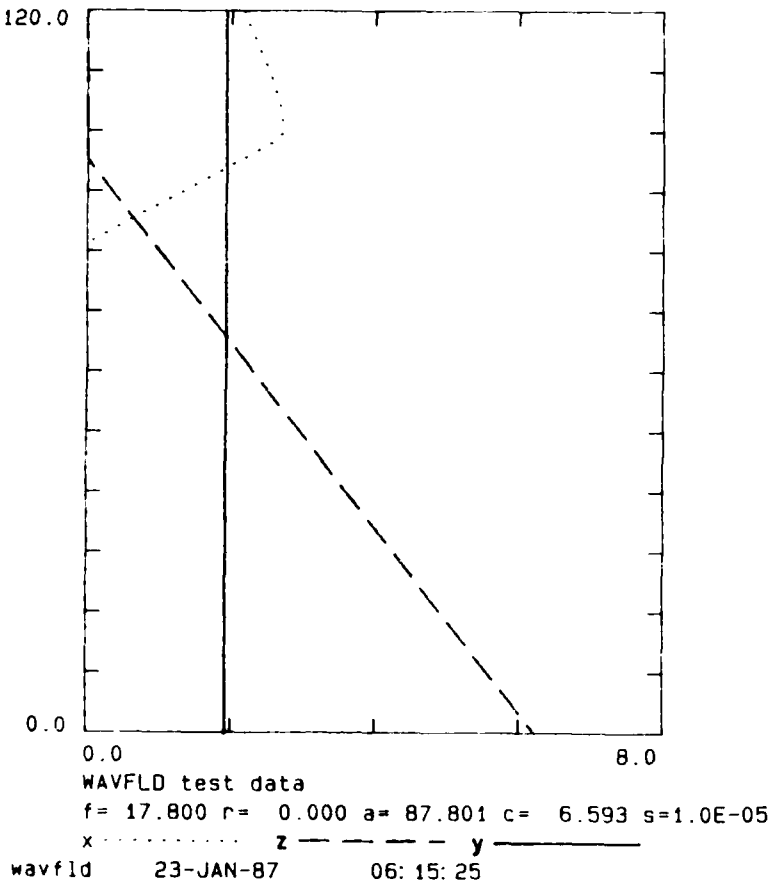


Figure 4. Plot of the magnetoionic terms X, Y and Z for the test case.

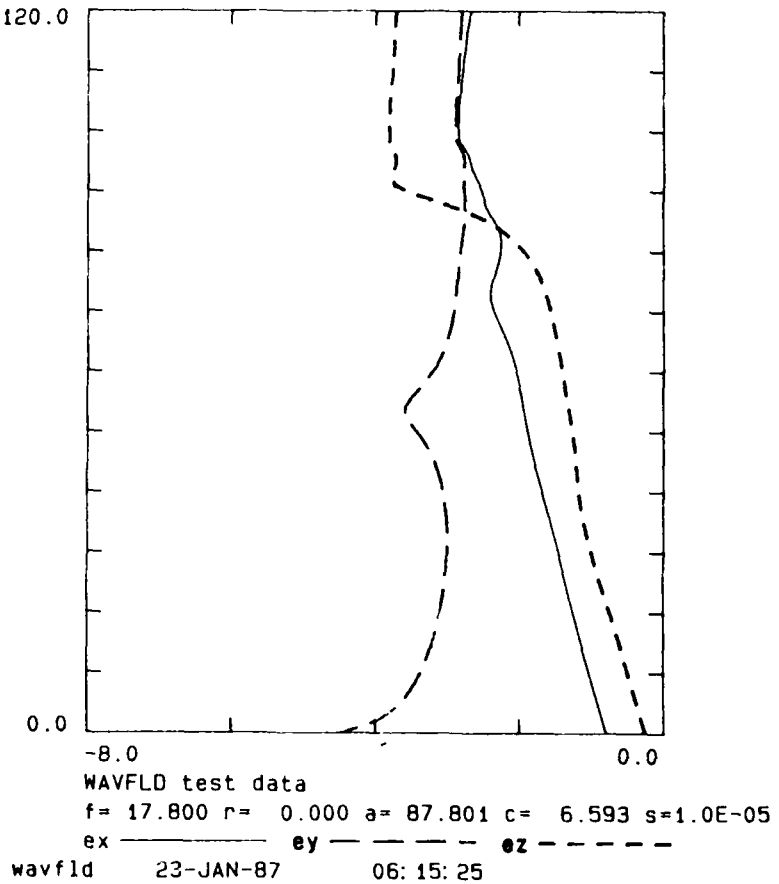


Figure 5. Total electric field components for the test case.

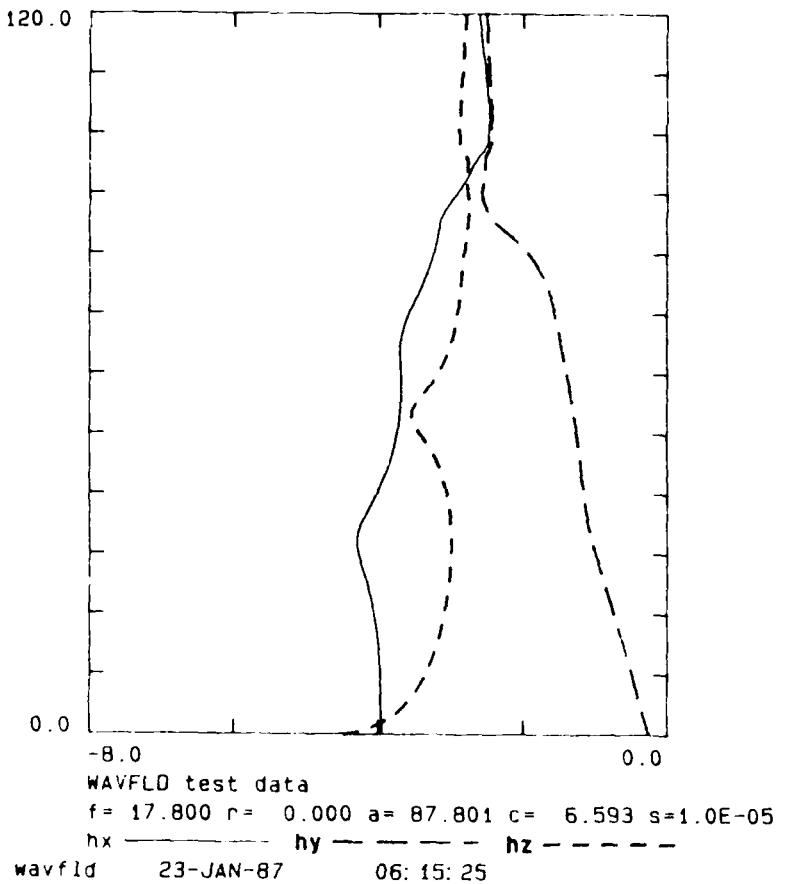


Figure 6. Total magnetic field components for the test case.

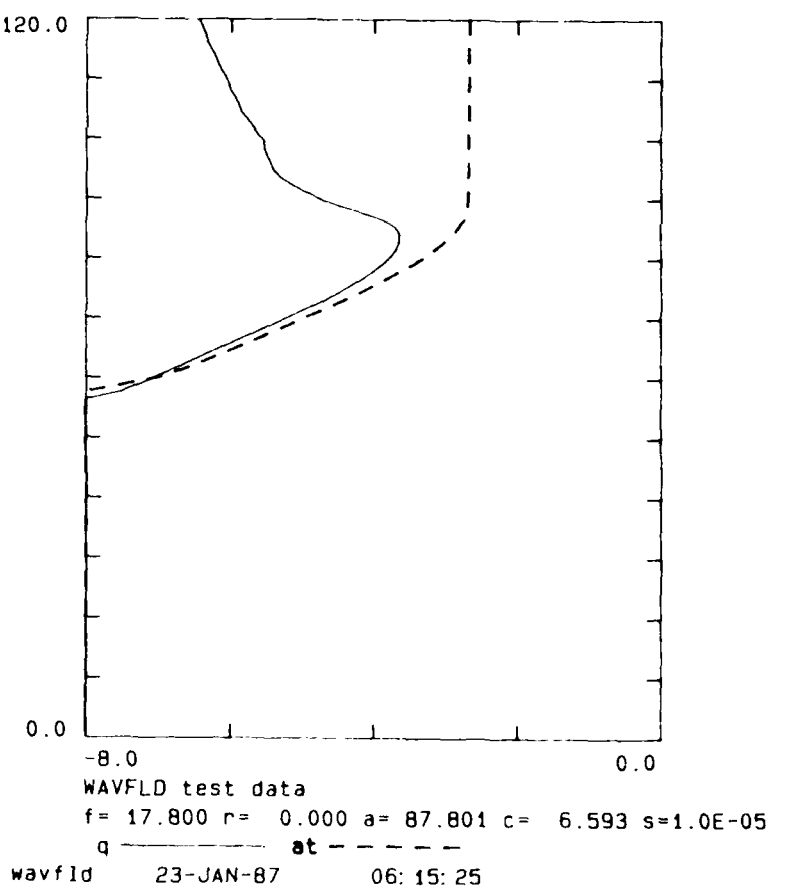


Figure 7. Relative Joule heating and absorption for the test case.

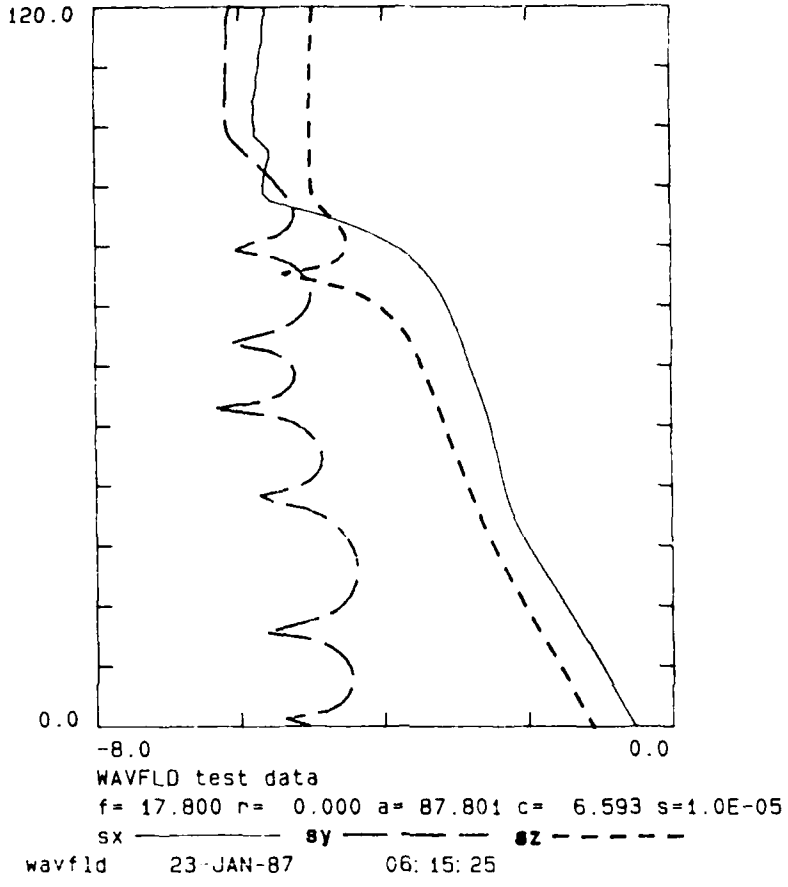


Figure 8. Components of the Poynting vector for the test case.

## REFERENCES


1. Ferguson, J. A., and F. P. Snyder, "Approximate VLF/LF Waveguide Mode Conversion Model," NOSC TD 400, November 1980.

2. Ferguson, J. A., and F. P. Snyder, "The Segmented Waveguide Program for Long Wavelength Propagation Calculations," NOSC TD 1071, April 1987.

3. Pappert, R. A., and L. R. Shockey, "Ionospheric Reflection and Absorption Properties of Normal Modes at ELF," DNA Interim Report 772, September 1977.

4. Shellman, C. H., "A New Version of MODESRCH Using Interpolated Values of the Magnetoionic Reflection Coefficients," NOSC TR 1143, August 1986.

# APPENDIX A

# SOURCE LISTING FOR PROGRAM WAVFLD

```
c      wavfld
c
c      namelist:  nprof,beta,hprime,sclhts,
c                 h,alpha,prec,debug,nelect,
c                 coefnu,expnu,charge,mratio,
c                 topht,lwstht,itr,maxitr,dtheta,lub,
c                 nprint,savplt
c
c      nprint=0   gives no print
c             1          print of total fields etc.
c             2          print of individual modes
c
c      savplt=t   writes data to unit 10 for processing by wfplts
c            =f   no output to unit 10
c
       implicit real*8 (a-h,o-z)
       common/wfinpt/thetap,freq,azim,codip,magfld,coefnu(5),expnu(5),
      $       topht,lwstht,delht,h,alpha,sigma,epsr,nelect
       common/wf flag/prec,iso,debug
       common/wf prof/htlist(101),lnlist(101,5),hlist(25),cflist(25,5),
      $       nrlht,lht,nrmht,mht,charge(5),mratio(5),nrspec
       common/itrat/dtheta(2),lub(2),maxitr,itr
       common/m mtx/m11,m21,m31,m12,m22,m32,m13,m23,m33
       dimension en(5),nu(5),label(2),plotx(101,16),ploty(101),
      $           ex(101), ey(101), ez(101), hx(101), hy(101), hz(101),
      $          sex(101),sey(101),sez(101),shx(101),shy(101),shz(101),
      $          sm11(101),sm21(101),sm31(101),
      $          sm12(101),sm22(101),sm32(101),
      $          sm13(101),sm23(101),sm33(101)
       complex*16 mi/(0.d0,-1.d0)/,theta,thetap,st,stp,exc,temp1,temp2,
      $           ex,ey,ez,hx,hy,hz,sex,sey,sez,shx,shy,shz,
      $           sm11,sm21,sm31,sm12,sm22,sm32,sm13,sm23,sm33,
      $           m11,m21,m31,m12,m22,m32,m13,m23,m33,e1,e2,e3,h1,h2,h3
       real*8 magfld,nu,mratio,lnlist,lwstht,lub
       real*4 plotx,ploty,capy,frq,rho,azm,cdp,sig,tpht,lwht,attn
       logical first/.true./,savplt
       integer debug,hdate(3),htime(2)
       character*8  ctime,branch,bcd(10),label/'        ','total   '/
       character*9  cdate
c
       equivalence (cdate,hdate),(ctime,htime)
       namelist/datum/h,alpha,prec,debug,nelect,
      $         coefnu,expnu,charge,mratio,nprof,beta,hprime,sclhts,
      $         topht,lwstht,itr,maxitr,dtheta,lub,
      $         nprint,savplt
c
       data dtr/1.745329252d-2/,npflag,nuflag/2*0/,
      $     nprof/0/,beta,hprime/2*0.d0/,sclhts/5.d0/,
      $     nprint/1/,savplt/.true./
c
       data freq/0.d0/,azim/0.d0/,codip/0.d0/,magfld/0.d0/,
      $     coefnu/1.816d11,4*4.54d9/,expnu/5*-.15d0/,
      $     topht/100./,lwstht/0.d0/,nrht/101/,h/0.d0/,alpha/3.14d-4/,
      $     sigma/5.d0/,epsr/81.d0/,nelect/0/,
      $     prec/3.d-5/,debug/0/,
      $     charge/-1.d0,1.d0,-1.d0,1.d0,-1.d0/,mratio/1.d0,4*5.8d4/,
      $     itr/0/,maxitr/10/,dtheta/5.d-2,1.d-2/,lub/5.d-2,5.d-3/
c
```

```
      call date(cdate)
      call time(ctime)
      print 1000,cdate,ctime
c
10    read(5,180,end=999) bcd
      print 181,bcd
      if(bcd(1) .eq. 'quit    ' .or.
     $   bcd(1) .eq. 'QUIT    ') go to 999
      if(bcd(1) .eq. 'name    ' .or.
     $   bcd(1) .eq. 'NAME    ') go to 20
      if(bcd(1) .eq. 'profile ' .or.
     $   bcd(1) .eq. 'PROFILE ') go to 30
      if(bcd(1) .eq. 'colfreq ' .or.
     $   bcd(1) .eq. 'COLFREQ ') go to 50
      if(bcd(1) .eq. 'data    ' .or.
     $   bcd(1) .eq. 'DATA    ') go to 60
      if(bcd(1) .eq. 'ipsq xmt' .or.
     $   bcd(1) .eq. 'IPSQ XMT') go to 60
      if(bcd(1) .eq. 'sw   xmt' .or.
     $   bcd(1) .eq. 'SW   XMT') go to 60
      go to 910
c
c     namelist input
20    read(5,datum)
      print datum
      capk=1.-.5*alpha*h
      if(nprof .eq. 0) go to 25
      if(beta*hprime .eq. 0.d0) go to 913
      npflag=1
      nn=hprime+sclhts/beta+.5d0
      nrspec=1
      c0=dlog(7.85535d-05*coefnu(1))-beta*hprime
      c1=beta+expnu(1)
      nrlht=2
      htlist(1)=topht
      htlist(2)=0.d0
      do 24 l=1,2
24    lnlist(l,1)=c0+c1*htlist(l)
c
c     number of points set to 101
25    delht=(topht-lwstht)/100.d0
26    if(nuflag .eq. 1) go to 10
      nrmht=2
      hlist(1)=topht
      hlist(2)=0.d0
      do 27 k=1,nrspec
      cflist(2,k)=dlog(coefnu(k))
27    cflist(1,k)=cflist(2,k)+topht*expnu(k)
      go to 10
c
c     profile input
30    decode(9,170,bcd) branch,nn
      npflag=1
      nrspec=nn
      if(nrspec .eq. 0) nrspec=1
      read(5,180) bcd
      print 181,bcd
      l=0
```

```
31    read(5,140) ht,en
      if(ht .lt. 0.d0) go to 39
      if(l .eq. 101) go to 912
      if(l .eq.   0) go to 32
      if(ht .ge. htlist(l)) go to 911
32    l=l+1
      if(nrspec .eq. 3) en(3)=en(2)-en(1)
      print 141,ht,(en(k),k=1,nrspec)
      htlist(l)=ht
      do 33 k=1,nrspec
33    lnlist(l,k)=dlog(dmax1(en(k),1.d-20))
      go to 31
39    nrlht=l
      go to 10
c
c     collision frequency profiles
50    nuflag = 1
      l=0
51    read(5,140) ht,nu
      if(ht .lt. 0.d0) go to 59
      if(l .eq. 25) go to 912
      if(l .eq.  0) go to 52
      if(ht .ge. hlist(l)) go to 911
52    l=l+1
      print 141,ht,(nu(k),k=1,nrspec)
      hlist(l)=ht
      do 53 k=1,nrspec
53    cflist(l,k)=dlog(dmax1(nu(k),1.d-20))
      go to 51
59    nrmht=l
      go to 10
c
c     wavefields calculations
60    if(npflag .eq. 0) go to 915
      read(5,180) bcd
61    read(5,1010) r,f,a,c,b,s,e
      if(r .eq. 40.d0) go to 300
      if(s .eq. 0.d0) go to 61
      rho=r
      freq=f
      azim=a
      codip=c
      magfld=b
      b=b*1.d4
      dcl= dsin(codip*dtr)*dcos(azim*dtr)
      dcm= dsin(codip*dtr)*dsin(azim*dtr)
      dcn=-dcos(codip*dtr)
      sigma=s
      epsr=e
      omega=6.28318530718d03*freq
      coefx=3.182357d09/omega**2
      capy=1.758796d11*magfld/omega
      wn=20.95845d0*freq
      const=-freq
      aconst=-8.686d0*wn
      econst=-.035d0*wn
      nsum=1
      nm=0
```

```
      if(nprint .le. 1) go to 62
      print 160
      print 181,bcd
      print 1011,r,f,a,c,b,s,e,h
62    read(5,1023) indx1,tr1,ti1,tmpr1,tmpi1,tmpr2,tmpi2
      if(tr1 .eq. 0.d0) go to 91
      nm=nm+1
      read(5,1023) indx2,tr2,ti2,tmpr3,tmpi3,tmpr4,tmpi4
      if(tr1 .ne. tr2 .or. ti1 .ne. ti2) go to 916
      thetap=dcmplx(tr1,ti1)
      if(tmpr1 .eq. 0.d0 .and. tmpi1 .eq. 0.d0) tmpr1=1.d-20
      temp1=dcmplx(tmpr1,tmpi1)
      if(indx1 .eq. 1) go to 63
      if(tmpr3 .eq. 0.d0 .and. tmpi3 .eq. 0.d0) tmpr3=1.d-20
      temp1=dcmplx(tmpr3,tmpi3)
c
63    stp=cdsin(thetap*dtr)
      sr=stp
      si=stp*mi
      atten=aconst*si
      voverc=1.d0/sr
      exc=(-2.124292957d0,0.d0)*temp1*stp*stp
      excr=dcmplx(0.d0,econst)*exc
      exci=dcmplx(0.d0,econst)*exc*mi
      wm=10.d0*dlog10(excr**2+exci**2)
      wa=datan2(exci,excr)
      if(h .eq. 0.d0) go to 64
      st=stp*capk
      theta=mi*cdlog(cdsqrt(1.d0-st*st)-mi*st)/dtr
      go to 65
64    theta=thetap
65    if(nprint .le. 1) go to 66
      print 160
      print 181,bcd
      print 1011,r,f,a,c,b,s,e,h
66    print 1040,nm,theta,atten,voverc,wm,wa,thetap
c
      call wavfld(ex,ey,ez,hx,hy,hz)
c
74    lht=0
      ht=topht
      temp2=exc
      if(nprint .gt. 1) go to 75
      if(nprint .gt. 0 .and. nsum .eq. 1) go to 80
75    print 900,label(nsum)
80    do 90 k=1,nrht
      j=nrht+1-k
      if(nsum .eq. 1) go to 81
      e1=sex(j)
      e2=sey(j)
      e3=sez(j)
      h1=shx(j)
      h2=shy(j)
      h3=shz(j)
      go to 82
81    e1=ex(j)
      e2=ey(j)
      e3=ez(j)
```

```
      h1=hx(j)
      h2=hy(j)
      h3=hz(j)
      if(nm .eq. 1) go to 83
82    m11=sm11(j)
      m21=sm21(j)
      m31=sm31(j)
      m12=sm12(j)
      m22=sm22(j)
      m32=sm32(j)
      m13=sm13(j)
      m23=sm23(j)
      m33=sm33(j)
      if(nsum .eq. 2) go to 84
      sex(j)=sex(j)+ex(j)*temp2
      sey(j)=sey(j)+ey(j)*temp2
      sez(j)=sez(j)+ez(j)*temp2
      shx(j)=shx(j)+hx(j)*temp2
      shy(j)=shy(j)+hy(j)*temp2
      shz(j)=shz(j)+hz(j)*temp2
      go to 84
83    call tmtrx(ht)
      sex(j)=ex(j)*temp2
      sey(j)=ey(j)*temp2
      sez(j)=ez(j)*temp2
      shx(j)=hx(j)*temp2
      shy(j)=hy(j)*temp2
      shz(j)=hz(j)*temp2
      sm11(j)=m11
      sm21(j)=m21
      sm31(j)=m31
      sm12(j)=m12
      sm22(j)=m22
      sm32(j)=m32
      sm13(j)=m13
      sm23(j)=m23
      sm33(j)=m33
c...  q and s are relative
84    q=dcmplx(0.d0,const)*(dconjg(m11*e1+m12*e2+m13*e3)*e1
     $                     +dconjg(m21*e1+m22*e2+m23*e3)*e2
     $                     +dconjg(m31*e1+m32*e2+m33*e3)*e3)
      suma=suma+q*delht
      sx=e2*dconjg(h3)-dconjg(h2)*e3
      sy=e3*dconjg(h1)-dconjg(h3)*e1
      sz=e1*dconjg(h2)-dconjg(h1)*e2
      exm=cdabs(e1)
      eym=cdabs(e2)
      ezm=cdabs(e3)
      hxm=cdabs(h1)
      hym=cdabs(h2)
      hzm=cdabs(h3)
      exa=cdang(e1)
      eya=cdang(e2)
      eza=cdang(e3)
      hxa=cdang(h1)
      hya=cdang(h2)
      hza=cdang(h3)
      if(nsum .eq. 1) go to 87
```

```
      ploty(k)=ht
c     joule heating term
      plotx(k,1)=dlog10(dmax1(1.d-10,dabs(q )))
c     attenuation
      plotx(k,2)=suma
c     poynting vector magnitudes
      plotx(k,3)=dlog10(dmax1(1.d-10,dabs(sx)))
      plotx(k,4)=dlog10(dmax1(1.d-10,dabs(sy)))
      plotx(k,5)=dlog10(dmax1(1.d-10,dabs(sz)))
      angl=datan2(sz,sx)/dtr
      ang2=datan2(sz,sy)/dtr
      ang3=dacos((dcl*sx+dcm*sy+dcn*sz)/sqrt(sx**2+sy**2+sz**2))/dtr
c     angles between poynting vectors
      plotx(k,6)=angl
      plotx(k,7)=ang2
      plotx(k,8)=ang3
      call wfdens(ht,en,nu)
      capx=coefx*en(1)
      capz=nu(1)/omega
c     ionospheric parameters
      plotx(k, 9)=dlog10(dmax1(1.d-10,dabs(capx)))
      plotx(k,10)=dlog10(dmax1(1.d-10,dabs(capz)))
c     magnitude of electric field vectors
      plotx(k,11)=dlog10(dmax1(1.d-10,exm))
      plotx(k,12)=dlog10(dmax1(1.d-10,eym))
      plotx(k,13)=dlog10(dmax1(1.d-10,ezm))
c     magnitude of magnetic field vectors
      plotx(k,14)=dlog10(dmax1(1.d-10,hxm))
      plotx(k,15)=dlog10(dmax1(1.d-10,hym))
      plotx(k,16)=dlog10(dmax1(1.d-10,hzm))
      if(nprint .gt. 0) go to 88
      go to 89
87    if(nprint .le. 1) go to 89
88    print 901,ht,exm,exa,eym,eya,ezm,eza,q,sx,sy,sz,angl,ang2,
     $             hxm,hxa,hym,hya,hzm,hza
89    ht=ht-delht
      if(ht .lt. htlist(lht+1)) lht=lht+1
      if(ht .lt.  hlist(mht+1)) mht=mht+1
90    continue
c
      if(nsum .ne. 2) go to 62
      go to 92
91    nsum=2
      suma=0.
      if(nprint .eq. 0) go to 74
      print 160
      print 181,bcd
      print 1011,r,f,a,c,b,s,e,h
      print 1012,capy,nm
      go to 74
c
92    if(savplt) then
c
        if(first) then
          first=.false.
          open(unit=10,type='new',form='unformatted')
        end if
        rho=r
```

```
        frq=freq
        azm=azim
        cdp=codip
        sig=sigma
        tpht=topht
        lwht=lwstht
        attn=suma
c       save plot data on a file for later
        write(10) bcd,hdate,htime,frq,rho,azm,cdp,sig,capy,
     $            nrht,tpht,lwht,attn,plotx,ploty
c
      end if
      go to 61
c
300   if(nprint .gt. 0) print 160
      go to 10
c
910   print 9910
      go to 999
911   print 9911
      go to 999
912   print 9912
      go to 999
913   print 9913
      go to 999
914   print 9914
      go to 999
915   print 9915
      go to 999
916   print 9916
999   stop
140   format(f7.2,4x,5(1x,e9.2))
141   format(f8.2,4x,1p5e9.2)
160   format(1h1)
161   format(1h )
170   format(1a8,1i1)
171   format(1x,1a8)
180   format(10a8)
181   format(1x,10a8)
900   format('0',a5,' Field strengths computed by WAVFLD'/
     $       '0   ht',6x,'mag -- x -- ang   mag -- y -- ang',
     $       3x,'mag -- z -- ang   q',10x,'sx',9x,'sy',9x,'sz',
     $       12x,'alpha',6x,'beta')
901   format(1x,f5.1,'  e',3(1pe11.3,0pf7.3),1p4e11.3,0p2f11.3/
     $       8x,       'h',3(1pe11.3,0pf7.3))
1000  format(' Additional plot identification:  ',a9,2x,a8/)
1010  format(1x,f7.3,2x,f8.4,2x,f8.3,2x,f8.3,2x,e10.3,2x,e10.3,2x,f5.1)
1011  format('0r',f7.3,' f',f8.4,' a',f8.3,' c',f8.3,' m',f6.3,
     $       ' s',1pe10.3,' e',0pf5.1,' h',f5.1)
1012  format('+',72x,' mag(y)',1pe10.3,' modes',i2)
1023  format(i1,2f9.0,1x,4e15.0)
1024  format('0input for nm = ',i2,':  ',i1,0p2f10.5,1p2e16.8/
     $       21x,                      i1,0p2f10.5,1p2e16.8)
1040  format('0mode    real      imag      atten   v/c',9x,
     $       'wait''s exc     real''     imag'''/
     $       1x,i3,f11.5,f10.5,f9.3,f9.5,f10.3,f7.3,f10.5,f10.5)
9910  format(/' Error in control string')
9911  format(/' Heights in profile out of order')
```

```
9912  format(/' Too many heights in profile')
9913  format(/' BETA or HPRIME are 0.0')
9914  format(/' Number of output heights is greater than 101')
9915  format(/' No profile specified')
9916  format(/' Input data out of order')
      end
```

```
      subroutine wavfld(ex,ey,ez,hx,hy,hz)
c
c   wavfld calls for the downward integration, and then performs the
c   back substitution of normalizing values (saved as data by wfstor).
c   field strengths are computed at heights from topht to lwstht at
c   delht increments and are returned in ex, ey, ez, hx, hy, hz.
c
      implicit real*8 (a-h,o-z)
      common/wf inpt/theta,freq,azmuth,codip,magfld,ceffnu(5),expnu(5),
     $          topht,lwstht,delht,h,alpha,sigma,epslon,nglect
      common/wf flag/precsn,iso,idbg
      common/wf save/p(4,2),m31,m32,m33,ortho,anorm,bnorm,ht,levl
      common/cs/c,s,ci,si
      real*8 magfld,lwstht
      complex*16 theta,ex(1),ey(1),ez(1),hx(1),hy(1),hz(1),
     $           p,m31,m32,m33,ortho,c,s,ci,si,b(2),w(4),osum
c
      jht=topht/delht+1.01d0
      test=(jht-1)*delht-topht
      if(dabs(test) .gt. 1.d-4) go to 800
      mht=lwstht/delht+1.01d0
      test=(mht-1)*delht-lwstht
      if(dabs(test) .gt. 1.d-4) go to 800
      jht=min0(jht-mht+1,101)
      mht=1
c
c   iteration to satisfy modal equation
      call itrate
c
c   combine solutions at ground so that they satisfy boundary condition.
      call wf bndy(b)
c
c   perform back substitution of normalizing values.
   20 o sum=0.0
      proda=1.0
      prodb=1.0
      iht=mht
      call wf load
      go to 25
c
   21 o sum=o sum*anorm/bnorm+ortho
      proda=proda*anorm
      if(proda .lt. 1.0d-30) proda=0.0
      prodb=prodb*bnorm
      call wf load
      do 23 j=1,4
      p(j,2)=(p(j,2)-o sum*p(j,1))*prodb
   23 p(j,1)=p(j,1)*proda
c
c   compute field strengths at profile heights.
   25 do 26 j=1,4
   26 w(j)=p(j,1)*b(1)+p(j,2)*b(2)
      ex(iht)=w(1)
      ey(iht)=-w(2)
      ez(iht)=-(s*w(4)+m31*w(1)-m32*w(2))/(1.0+m33)
      hx(iht)=w(3)
      hy(iht)=w(4)
      hz(iht)=-s*w(2)
```

```
c
      iht=iht+1
      if(iht .le. jht)  go to 21
      if(levl .ne. 0) print 903,levl
      return
c
  800 print 902
      stop
c
  902 format('0error in wavfld'/
     $       ' delht does not divide topht-lwstht evenly')
  903 format('0levl not zero: levl=',i3)
      end
```

```
      subroutine wf intg(topht,lwstht,delht,iflag)
c
c   wf intg performs the integration of the p matrix down through the
c   ionosphere, using the techniques given by pitteway.
c   accuracy is maintained by adjusting the stepsize so that the
c   p matrix is computed with sufficient accuracy.
c
c   iflag=0  integ for theta only
c   iflag=1  integ for theta and theta-dtheta
c
      implicit real*8 (a-h,o-z)
      common/wf flag/precsn,iso,idbg
      common/p mtx/p(16),pi(16)
      common/wf save/p save(16),m31 sav,m32 sav,m33 sav,
     $          ortho,anorm,bnorm,ht,levl
      common/m mtx/m(3,3)
      common/wf prof/enht(101),enlog(101,5),collht(25),collfr(25,5),
     $          nrlht,lht,nrmht,mht,charge(5),ratiom(5),nrspec
      integer svflag
      real*8 lwstht
      complex*16 m31 sav,m32 sav,m33 sav,ortho,m
      dimension prevp(16),tempp(16),dpdh(16),pv dpdh(16),dpidh(16)
c
c   minimum step-size allowed
      data epsht/5.d-4/,dhmin/1.d-3/
c
      call init t
      call t mtrx(top ht)
      call wf init(p)
      call p deriv(p,dpdh)
      if(iflag .eq. 0) go to 11
      call ti mtrx
      call wf init(pi)
      call p deriv(pi,dpidh)
   11 continue
c
      isteps=0
      kmax=0
      levl=0
      ht=topht
      call xfer(p,p save,16)
      m31 sav=m(3,1)
      m32 sav=m(3,2)
      m33 sav=m(3,3)
      call wf stor
      wfht=topht-delht
      delh2=0.125d0*delht
      svflag=0
c
c   determine next stepsize to use.
10    if(svflag .eq. 1) delh2=savdh2
      svflag=0
      nodbl=0
      ht0=ht
      call xfer(p,prevp,16)
      call xfer(dpdh,pv dpdh,16)
      htlim=wfht
      if(enht(lht+1) .gt. htlim+epsht) htlim=enht(lht+1)
```

```
      if(collht(mht+1) .gt. htlim+epsht) htlim=collht(mht+1)
      if(ht0-delh2.ge.htlim+epsht)  go to 50
      savdh2=delh2
      svflag=1
      delh2=ht0-htlim
c
c   perform next integration step.
   50 call wf step(p,dpdh,ht,delh2,0)
      call xfer(p,tempp,16)
      m31 sav=m(3,1)
      m32 sav=m(3,2)
      m33 sav=m(3,3)
      ht=ht0
      call xfer(prevp,p,16)
      call xfer(pv dpdh,dpdh,16)
      delh=0.5*delh2
      call wf step(p,dpdh,ht,delh,1)
      call p deriv(p,dpdh)
      call wf step(p,dpdh,ht,delh,2)
c   check accuracy of result.
      pmax=0.0
      do 85 j=1,16
      pabs=dabs(p(j)-tempp(j))
      if(pmax .lt. pabs) pmax=pabs
   85 continue
c   adjust stepsize if necessary.
      if(pmax .lt. precsn)  go to 100
c
      if(delh .gt. dhmin)  go to 95
      if(kmax .eq. 0)  print 900, ht
      kmax=1
      go to 100
   95 continue
      delh2=0.5*delh2
      nodbl=1
      if(pmax .lt. 10.0*precsn)  go to 99
      delh2=0.25*delh2
      nodbl=0
   99 continue
      ht=ht0
      call xfer(prevp,p,16)
      call xfer(pv dpdh,dpdh,16)
      svflag=0
      go to 50
c
  100 call wf scal(p,0)
      call xfer(p,p save,16)
      if(ht .lt. wfht+epsht) call wf stor
      call p deriv(p,dpdh)
      if(iflag .eq. 0) go to 72
      ht=ht0
      call wf step(pi,dpidh,ht,delh,3)
      call p deriv(pi,dpidh)
      call wf step(pi,dpidh,ht,delh,4)
      call wf scal(pi,1)
      call p deriv(pi,dpidh)
   72 continue
c
```

```
      isteps=isteps+1
      if(idbg .eq. 0) go to 73
      idiv=isteps/50
      if(isteps .eq. 50*idiv) print 902,isteps,ht
   73 continue
      if(no dbl .eq. 0 .and. pmax .lt. 0.1*precsn) delh2=2.0*delh2
c
c    check integration and profile heights.
      if(ht .lt. lwstht+epsht)  go to 80
      if(ht .lt. wfht+epsht)  wfht=wfht-delht
      if(ht .lt. enht(lht+1)+epsht)  lht=lht+1
      if(ht .lt. collht(mht+1)+epsht)  mht=mht+1
      go to 10
c
   80 print 901,isteps
      return
c
  900 format('0minimum stepsize used at ht=',1pe14.5)
  901 format('0',i4,' integration steps used in wavfld')
  902 format('0',i4,' integration steps, ht=',f9.4)
      end
```

```
      subroutine wf scal(pp,iflag)
c
c   wfscal scales and orthogonalizes the solution vectors p.
c   this scaling must later be removed to yield correct (unscaled)
c   solutions.
c
      implicit real*8 (a-h,o-z)
      common/wf save/p save(16),m31 sav,m32 sav,m33 sav,
     $          o sum,aprod,bprod,ht,levl
      common/save/p etc(27,101)
      complex*16 p(4,2),m31 sav,m32 sav,m33 sav,o sum,ortho
      dimension pr(8,2),pp(16)
      equivalence (p,pr)
c
      call xfer(pp,pr,16)
      anorm=0.0
      do 11 j=1,8
   11 anorm=anorm+pr(j,1)**2
      ortho=0.0
      do 12 j=1,4
   12 ortho=ortho+dconjg(p(j,1))*p(j,2)
      ortho=ortho/anorm
      do 13 j=1,4
   13 p(j,2)=p(j,2)-ortho*p(j,1)
      bnorm=0.0
      do 14 j=1,8
   14 bnorm=bnorm+pr(j,2)**2
      anorm=1.0/dsqrt(anorm)
      bnorm=1.0/dsqrt(bnorm)
      do 15 j=1,8
      pr(j,1)=pr(j,1)*anorm
   15 pr(j,2)=pr(j,2)*bnorm
      call xfer(pr,pp,16)
      if(iflag .ne. 0) return
      o sum=o sum+ortho*aprod/bprod
      aprod=aprod*anorm
      bprod=bprod*bnorm
      return
c                                                    entry wf stor
      entry wf stor
      levl=levl+1
      call xfer(p save,p etc(1,levl),27)
      o sum=0.0
      a prod=1.0
      b prod=1.0
      return
c                                                    entry wf load
      entry wf load
      call xfer(p etc(1,levl),p save,27)
      levl=levl-1
      return
      end
```

```
      subroutine wf step(p,dpdh,ht,delh,iflag)
c
c   wf step increments the solution of p from ht to ht-delh,
c   using runge-kutta integration
c
c   iflag=0  one large step, theta
c   iflag=1  first small step, theta
c   iflag=2  second small step, theta
c   iflag=3  first small step, theta-dtheta
c   iflag=4  second small step, theta-dtheta
c
      implicit real*8 (a-h,o-z)
      common/wf con/omega,wave nr
      common/wf flag/precsn,iso,idbg
      common/t mtx/t(18)
      common/tm mtx/tm(18)
      dimension p(16),dpdh(16),p0(16),
     $          hdelp0(16),delp1(16),delp2(16)
      dimension t save1(18),t save2(18),
     $          tm sav1(18),tm sav2(18),tm sav3(18),tm sav4(18)
c
      ht0=ht
      delh k=delh*wave nr
      hdelh k=delh k*0.5
      do 11 j=1,16
      p0(j)=p(j)
      hdelp0(j)=-dpdh(j)*hdelh k
   11 p(j)=p0(j)+hdelp0(j)
c
      ht=ht0-0.5*delh
      if(iflag .le. 2) call t mtrx(ht)
      if(iflag .eq. 0) call xfer(t,t save1,18)
      if(iflag .eq. 0) call xfer(tm,tm sav2,18)
      if(iflag .eq. 1) call xfer(tm,tm sav1,18)
      if(iflag .eq. 2) call xfer(tm,tm sav3,18)
      if(iflag .eq. 3) call xfer(tm sav1,tm,18)
      if(iflag .eq. 4) call xfer(tm sav3,tm,18)
      if(iflag .ge. 3) call ti mtrx
c
      call p deriv(p,dpdh)
      do 12 j=1,16
      delp1(j)=-dpdh(j)*delh k
   12 p(j)=p0(j)+0.5*delp1(j)
c
      call p deriv(p,dpdh)
      do 13 j=1,16
      delp2(j)=-dpdh(j)*delh k
   13 p(j)=p0(j)+delp2(j)
c
      ht=ht0-delh
      if(iflag .eq. 0) call t mtrx(ht)
      if(iflag .eq. 0) call xfer(t,t save2,18)
      if(iflag .eq. 1) call xfer(t save1,t,18)
      if(iflag .eq. 2) call xfer(t save2,t,18)
      if(iflag .eq. 0) call xfer(tm,tm sav4,18)
      if(iflag .eq. 3) call xfer(tm sav2,tm,18)
      if(iflag .eq. 4) call xfer(tm sav4,tm,18)
      if(iflag .ge. 3) call ti mtrx
```

```
c
      call p deriv(p,dpdh)
      third=1.0d0/3.0d0
      do 14 j=1,16
      delp4=(hdelp0(j)+delp1(j)+delp2(j)-dpdh(j)*hdelh k)*third
   14 p(j)=p0(j)+delp4
      return
      end
```

```
      subroutine xfer(a,b,n)
c
c   transfer array a into array b.
c
      real*8 a,b
      dimension a(1),b(1)
c
      do 11 j=1,n
   11 b(j)=a(j)
      return
      end
```

```
      subroutine wf dens (ht, en, coll)
c
c   wf dens computes the ion density and collision frequency for each
c   specie by logarithmic interpolation of the corresponding profiles.
c   profile values are interpolated between entries mht and mht+1
c   (lht and lht+1).
c
      implicit real*8 (a-h,o-z)
      common/wf prof/enht(101),enlog(101,5),collht(25),collfr(25,5),
     $          nrlht,lht,nrmht,mht,charge(5),ratiom(5),nrspec
      dimension  en(5), coll(5), dele(5), delc(5)
c
      if(lht .eq. 0) then
        lsave=0
   10   lht=lht+1
        if(ht .lt. enht(lht)) go to 10
        mht=0
        msave=0
   20   mht=mht+1
        if(ht .lt. collht(mht)) go to 20
      end if
      if(lht .ne. lsave) then
        if(lht .ge. nrlht) lht=nrlht-1
        delh=enht(lht+1)-enht(lht)
        do 150  k=1,nrspec
  150   dele(k)=(enlog(lht+1,k)-enlog(lht,k))/delh
        lsave=lht
      end if
      if(mht .ne. msave) then
        if(mht .ge. nrmht) mht=nrmht-1
        delh=collht(mht+1)-collht(mht)
        do 250  k=1,nrspec
  250   delc(k)=(collfr(mht+1,k)-collfr(mht,k))/delh
        msave=mht
      end if
      dh=ht-enht(lht)
      dc=ht-collht(mht)
      do 500  k=1,nrspec
      en(k)=dexp(enlog(lht,k)+dh*dele(k))
  500 coll(k)=dexp(collfr(mht,k)+dc*delc(k))
      return
      end
```

```
      subroutine wf init(p)
c
c  wf init computes the initial p matrix, i.e., the initial conditions
c  for the integration dp/dz=-ik*t*p.
c
      implicit real*8 (a-h,o-z)
      common/t mtx/t11,t31,t41,t12,t32,t42,t14,t34,t44
      common/wf flag/precsn,iso,idbg
      complex*16 b3,b2,b1,b0,i,q temp,det,sqroot,q(4),zp,
     $           t11,t31,t41,t12,t32,t42,t14,t34,t44
      dimension p(8,2)
      data i/(0.d0,1.d0)/
c
      if(iso .ne. 0) go to 50
c
      b3=-(t11+t44)
      b2=t11*t44-t14*t41-t32
      b1=-(-t32*(t11+t44)+t12*t31+t34*t42)
      b0=-t11*(t32*t44-t34*t42)
     $   +t12*(t31*t44-t34*t41)
     $   -t14*(t31*t42-t32*t41)
      call quartc(b3,b2,b1,b0,q)
c
      qi min=-i*q(1)
      j1=1
      do 22 j=2,4
      q imag=-i*q(j)
      if(q imag .gt. qi min) go to 22
      qi min=q imag
      j1=j
   22 continue
c
      qr max=q(1)
      j2=1
      do 23 j=2,4
      q real=q(j)
      if(q real .lt. qr max) go to 23
      qr max=q real
      j2=j
   23 continue
c
      if(j1 .eq. j2) go to 80
c
      q temp=q(j2)
      q(1)=q(j1)
      q(2)=q temp
c
      do 31 j=1,2
      det=(t11-q(j))*(t44-q(j))-t14*t41
      zp=(t12*q(j)-(t12*t44-t14*t42))/det
      p(1,j)=dreal(zp)
      p(2,j)=dimag(zp)
      p(3,j)=1.0
      p(4,j)=0.0
      zp=q(j)
      p(5,j)=dreal(zp)
      p(6,j)=dimag(zp)
      zp=(t42*q(j)+(t12*t41-t11*t42))/det
```

```
      p(7,j)=dreal(zp)
   31 p(8,j)=dimag(zp)
c
   40 if(idbg .lt. 2) return
      print 902,q
      print 901,p
      return
c
   50 b1=(t11+t44)*0.5
      b0=t11*t44-t14*t41
      sqroot=cdsqrt(b1**2-b0)
      q(1)=b1+sqroot
      q(4)=b1-sqroot
      sqroot=cdsqrt(t32)
      q(2)=+sqroot
      q(3)=-sqroot
c
      q1 test=q(1)+i*q(1)
      q4 test=q(4)+i*q(4)
      if(q4 test .gt. q1 test) q(1)=q(4)
      q2 test=q(2)+i*q(2)
      q3 test=q(3)+i*q(3)
      if(q3 test .gt. q2 test) q(2)=q(3)
c
      zp=t14
      p(1,1)=dreal(zp)
      p(2,1)=dimag(zp)
      p(3,1)=0.0
      p(4,1)=0.0
      p(5,1)=0.0
      p(6,1)=0.0
      zp=-(t11-q(1))
      p(7,1)=dreal(zp)
      p(8,j)=dimag(zp)
c
      p(1,2)=0.0
      p(2,2)=0.0
      p(3,2)=0.0
      p(4,2)=0.0
      zp=q(2)
      p(5,2)=dreal(zp)
      p(6,2)=dimag(zp)
      p(7,2)=0.0
      p(8,2)=0.0
      go to 40
c
   80 print 900,q
      stop
  900 format('0error in wf init, q values do not sort'/
     $       ' q=',4(1pe15.5,1pe13.5))
  901 format('0p values='/
     $       4(1pe15.5,1pe13.5)/4(1pe15.5,1pe13.5))
  902 format('0initial values from wf init at ht=topht'/
     $       ' q=',2(1pe15.5,1pe13.5))
      end
```

```
      subroutine quartc (fourb3, sixb2, fourbl, b0, q)
c
c   quartc finds the roots of a quartic polynomial from the closed form.
c
      implicit real*8 (a-h,o-z)
      complex*16 b3,b2,bl,b0,q,fourb3,sixb2,fourbl,b3sq,h,i,g,hprime,
     $           gprime,sqroot,pplus,p,logp,cbert0,cbert1,cbert2,omega1,
     $           omega2,rootp,rootq,rootr
      real*8 mgplus,mgmnus
      dimension q(4),pri(2)
      equivalence (p,pri)
c
      data omega1/(-.5d0, .8660254038d0)/,omega2/(-.5d0,-.8660254038d0)/
      data precsn/1.d-10/
c
      b3=fourb3*0.25
      b2=sixb2/6.0
      bl=fourbl*0.25
      b3sq=b3**2
      h=b2-b3sq
      i=b0-4.0*b3*bl+3.0*b2**2
      g=bl+b3*(-3.0*b2+2.0*b3sq)
      hprime=-i/12.0
      gprime=-g**2/4.0-h*(h**2+3.0*hprime)
      sqroot=cdsqrt(gprime**2+4.0*hprime**3)
      p=(-gprime+sqroot)*0.5
      mgplus=dabs(pri(1))+dabs(pri(2))
      pplus=p
      p=(-gprime-sqroot)*0.5
      mgmnus=dabs(pri(1))+dabs(pri(2))
      if(mgplus .gt. mgmnus) p=pplus
      logp=cdlog(p)
      cbert0=cdexp(logp/3.0)
      cbert1=omega1*cbert0
      cbert2=omega2*cbert0
      rootp=cdsqrt(cbert0-hprime/cbert0-h)
      rootq=cdsqrt(cbert1-hprime/cbert1-h)
      rootr=cdsqrt(cbert2-hprime/cbert2-h)
      if(cdabs(g) .le. 1.0d-20) go to 5
      sign=-rootp*rootq*rootr*2.0/g
      if(sign .lt. 0.0) rootr=-rootr
c
5     q(1)=+rootp+rootq+rootr-b3
      q(2)=+rootp-rootq-rootr-b3
      q(3)=-rootp+rootq-rootr-b3
      q(4)=-rootp-rootq+rootr-b3
c
      do 20 n=1,4
      iter=0
10    rootp=q(n)**4+fourb3*q(n)**3+sixb2*q(n)**2+fourbl*q(n)+b0
      rootq=4.0*q(n)**3+3.0*fourb3*q(n)**2+2.0*sixb2*q(n)+fourbl
      rootr=rootp/rootq
      q(n)=q(n)-rootr
      if(cdabs(rootr) .lt. precsn)  go to 20
      iter=iter+1
      if(iter .lt. 10) go to 10
      print 900, iter, q(n)
20    continue
```

```
c
      return
900   format(i3,' iterations, q=',e15.5,e13.5,' fails to converge')
      end
```

```
      subroutine rbars(c,s,rbar11,rbar22,ey,hy)
C
      implicit real*8 (a-h,o-z)
      common/wf inpt/theta,freq,azim,codip,magfld,coefnu(5),expnu(5),
     $          topht,lwstht,delht,h,alpha,sigma,epsr,nelect
      common/wf con/omega,k
      common/ey grnd/eyg,hyg
      complex*16 theta,i,ngsq,c,s,ssq,sqroot,rtiort,ikc,
     $           p0,h10,h20,h1prm0,h2prm0,caph10,caph20,
     $           pd,h1d,h2d,h1prmd,h2prmd,caph1d,caph2d,
     $           pz,h1z,h2z,h1prmz,h2prmz,
     $           alst,a2nd,a3rd,a4th,a1,a2,a3,a4,
     $           exd,exdsq,exz,exzsq,
     $           rbar11,rbar22,z1,z2,
     $           den12,den34,
     $           eyg,hyg,
     $           ex,ey,ez,hx,hy,hz
      real*8 k,kvraot,kvratt,n0sq,ndsq,nzsq,magfld,lwstht
      equivalence (pz,pd),(h1z,h1d),(h2z,h2d),(h1prmz,h1prmd),
     $            (h2prmz,h2prmd),(exd,exz),(exdsq,exzsq)
C
      data i/(0.0d0,1.0d0)/
      data tstthm/10.d0/
      data epsln0/8.85434d-12/
C
      eyg=1.0
      hyg=1.0
      alt=lwstht
      d=lwstht
      ssq=s*s
      ngsq=dcmplx(epsr,-sigma/(omega*epsln0))
      sqroot=cdsqrt(ngsq-ssq)
      thtim=i*theta
      if(thtim .gt. tstthm) go to 10
C
      kvraot=dexp(dlog(k/alpha)/3.0)
      kvratt=kvraot**2
      avrkot=1.0/kvraot
      avrktt=avrkot**2*0.5
      n0sq=1.0-alpha*h
      rtiort=n0sq/ngsq*sqroot
      p0=kvratt*(n0sq-ssq)
      call mdhnkl (p0,h10,h20,h1prm0,h2prm0,theta,'rb 1')
      caph10=h1prm0+avrktt*h10
      caph20=h2prm0+avrktt*h20
      alst=caph20-i*rtiort*kvraot*h20
      a2nd=caph10-i*rtiort*kvraot*h10
      a3rd=h2prm0-i*kvraot*sqroot*h20
      a4th=h1prm0-i*kvraot*sqroot*h10
      den12=h20*a2nd-h10*alst
      den34=h20*a4th-h10*a3rd
      if(d .eq. 0.0) go to 10
C
      ndsq=1.0-alpha*(h-d)
      pd=kvratt*(ndsq-ssq)
      call mdhnkl (pd,h1d,h2d,h1prmd,h2prmd,theta,'rb 2')
      caph1d=h1prmd+avrktt*h1d
      caph2d=h2prmd+avrktt*h2d
```

```
c
      a1=c*ndsq*(h2d*a2nd-h1d*alst)
      a2=i*avrkot*(caph1d*alst-caph2d*a2nd)
      a3=i*avrkot*(h2prmd*a4th-h1prmd*a3rd)
      a4=c*(h2d*a4th-h1d*a3rd)
      rbar11=(a1-a2)/(a1+a2)
      rbar22=(a3+a4)/(a4-a3)
      expon=dexp(0.5*alpha*alt)
      hy=(h2z*a2nd-h1z*alst)*expon/den12*hyg
      ey=(h2z*a4th-h1z*a3rd)/den34*eyg
      return
c
c     flat earth
   10 ikc=i*k*c
      exd=cdexp(-ikc*d)
      exdsq=exd**2
      z1=(ngsq*c-sqroot)/(ngsq*c+sqroot)
      z2=(c-sqroot)/(c+sqroot)
      rbar11=z1*exdsq
      rbar22=z2*exdsq
      hy=(1.0+z1*exzsq)/(1.0+z1)/exz*hyg
      ey=(1.0+z2*exzsq)/(1.0+z2)/exz*eyg
      return
c                                                    entry wf htgn
      entry wf htgn(ht,ex,ey,ez,hx,hy,hz,c,s)
      alt=ht
      if(thtim .gt. tstthm) go to 50
      nzsq=1.0-alpha*(h-alt)
      pz=kvratt*(nzsq-ssq)
      call mdhnkl(pz,h1z,h2z,h1prmz,h2prmz,theta,'htgn')
      expon=dexp(0.5*alpha*alt)
      hy=(h2z*a2nd-h1z*alst)*expon/den12*hyg
      ey=(h2z*a4th-h1z*a3rd)/den34*eyg
      ex=i*avrkot*((h2prmz*a2nd-h1prmz*alst)/
     $   den12*hyg*expon+avrktt*hy)/nzsq
      ez=-s/nzsq*hy
      hz=s*ey
      hx=avrkot/i*(h2prmz*a4th-h1prmz*a3rd)/den34*eyg
      return
c
c     flat earth
   50 exz=cdexp(-ikc*alt)
      exzsq=exz**2
      hy=(1.0+z1*exzsq)/(1.0+z1)/exz*hyg
      ey=(1.0+z2*exzsq)/(1.0+z2)/exz*eyg
      ex=-c*(1.0-z1*exzsq)/(1.0+z1)/exz*hyg
      ez=-s*hy
      hz=s*ey
      hx=c*(1.0-z2*exzsq)/(1.0+z2)/exz*eyg
      return
      end
```

```
      subroutine r mtrx(p,cosn,r)
c
c    r mtrx computes reflection coefficient matrix from p matrix
c    and returns it in r.
c
      implicit real*8 (a-h,o-z)
      complex*16 zp(4,2),cosn,r(2,2),
     $           g12, g13, g14, g23, g24, g34,
     $           d00, d11, d22, d12, d21
      dimension p(8,2)
c
      do 2 j=1,2
      zp(1,j)=dcmplx(p(1,j),p(2,j))
      zp(2,j)=dcmplx(p(3,j),p(4,j))
      zp(3,j)=dcmplx(p(5,j),p(6,j))
2     zp(4,j)=dcmplx(p(7,j),p(8,j))
c
      g12=zp(1,1)*zp(2,2)-zp(1,2)*zp(2,1)
      g13=zp(1,1)*zp(3,2)-zp(1,2)*zp(3,1)
      g14=zp(1,1)*zp(4,2)-zp(1,2)*zp(4,1)
      g23=zp(2,1)*zp(3,2)-zp(2,2)*zp(3,1)
      g24=zp(2,1)*zp(4,2)-zp(2,2)*zp(4,1)
      g34=zp(3,1)*zp(4,2)-zp(3,2)*zp(4,1)
c
      d00=-g13+cosn*( g34-g12+cosn*g24)
      d11= g13+cosn*( g34+g12+cosn*g24)
      d22= g13+cosn*(-g34-g12+cosn*g24)
      d12=2.0*cosn*g14
      d21=2.0*cosn*g23
c
      r(1,1)=d11/d00
      r(2,2)=d22/d00
      r(1,2)=d12/d00
      r(2,1)=d21/d00
      return
      end
```

```
      subroutine t mtrx(ht)
c
c   t mtrx computes m- the susceptibility tensor and
c                    t- the coefficient matrix of dp/dz=-ik*t*p.
c   note that on call to entry init t, various ionospheric
c   constants are computed.
c
      implicit real*8 (a-h,o-z)
      common/wf flag/precsn,iso,idbg
      common/m mtx/m11,m21,m31,m12,m22,m32,m13,m23,m33
      common/t mtx/t11,t31,t41,t12,t32,t42,t14,t34,t44
      common/tm mtx/tm11,tm31,tm41,tm12,tm32,tm42,tm14,tm34,tm44
      common/cs/c,s,ci,si
      common/wf inpt/theta,freq,azmuth,codip,magfld,ceffnu(5),expnu(5),
     $          topht,lwstht,delht,h,alpha,sigma,epslon,nglect
      common/itrat/dtheta,dlub(2),maxitr,itr
      common/wf con/omega,wave nr
      common/wf prof/enht(101),enlog(101,5),collht(25),collfr(25,5),
     $          nrlht,lht,nrmht,mht,charge(5),ratiom(5),nrspec
      real*8 magfld,lwstht,lsqysq,msqysq,nsqysq,lmysq,lnysq,mnysq,
     $       nu,ly,my,ny
      complex*16 m(3,3),
     $           m11,m21,m31,m12,m22,m32,m13,m23,m33,
     $           t11,t31,t41,t12,t32,t42,t14,t34,t44,
     $           tm11,tm31,tm41,tm12,tm32,tm42,tm14,tm34,tm44,
     $           c,s,ci,si,csq,ssq,csqi,ssqi,
     $           theta,dtheta,
     $           d,m13d,m23d,
     $           u,usq,dd,i,iud,ta,tb
      dimension y(5),ysq(5),ly(5),my(5),ny(5),coef en(5),en(5),nu(5),
     $          lmysq(5),lnysq(5),mnysq(5),lsqysq(5),msqysq(5),nsqysq(5)
      equivalence (m11,m)
c
      data pi/3.141592653d0/
      data twopi/6.28318530717959d0/
      data dtr/0.01745329252d0/
      data coeffx/3.182357d03/,coeffy/1.758796d11/
      data i/(0.d0,1.d0)/
      data vellt/2.997928d05/
c
c   calculate the matrix m.
      m(1,1)=0.0
      m(1,2)=0.0
      m(1,3)=0.0
      m(2,1)=0.0
      m(2,2)=0.0
      m(2,3)=0.0
      m(3,1)=0.0
      m(3,2)=0.0
      m(3,3)=0.0
c
      call wf dens (ht, en, nu)
      nflag=0
      do 20 k=1,nrspec
c   add in the contributions to the susceptibility tensor m for each
c   specie in the ionosphere.
      if(en(k) .lt. 1.0d-3) go to 20
      nflag=1
```

```
      x=coef en(k)*en(k)
      if(nglect .ne. 0) x=-x
      z=nu(k)*ov omga
      if(nglect .ne. 0) z=-z
      u=1.0-i*z
      usq=u*u
      dd=-x/(u*(usq-ysq(k)) )
      iud=(z+i)*dd
      ta=usq*dd
      m(1,1)=m(1,1)+ta
      m(2,2)=m(2,2)+ta
      m(3,3)=m(3,3)+ta
      m(2,2)=m(2,2)-msqysq(k)*dd
      ta=my(k)*iud
      tb=lnysq(k)*dd
      m(1,3)=m(1,3)+ta-tb
      m(3,1)=m(3,1)-ta-tb
      if(iso .ne. 0) go to 20
      m(1,1)=m(1,1)-lsqysq(k)*dd
      m(3,3)=m(3,3)-nsqysq(k)*dd
      ta=ny(k)*iud
      tb=lmysq(k)*dd
      m(2,1)=m(2,1)+ta-tb
      m(1,2)=m(1,2)-ta-tb
      ta=ly(k)*iud
      tb=mnysq(k)*dd
      m(3,2)=m(3,2)+ta-tb
      m(2,3)=m(2,3)-ta-tb
   20 continue
c
      crvtrm=alpha*(h-ht)
      m(1,1)=m(1,1)-crvtrm
      m(2,2)=m(2,2)-crvtrm
      m(3,3)=m(3,3)-crvtrm
c
c   calculate the matrix t.
      d=1.0/(1.0+m33)
      tm41=1.0+m11
      tm32=m22
      tm14=d
      if(nflag .eq. 0) go to 40
      m13d=m13*d
      m23d=m23*d
      tm41=tm41-m31*m13d
      tm11=m31*d
      tm44=m13d
      if(iso .ne. 0) go to 40
      tm32=tm32-m32*m23d
      tm31=m31*m23d-m21
      tm12=m32*d
      tm42=m32*m13d-m12
      tm34=m23d
c
   40 t41=tm41
      t32=csq+tm32
      t14=1.0-ssq*tm14
      if(nflag .eq. 0) go to 70
      t11=-s*tm11
```

```
      t44=-s*tm44
      if(iso .ne. 0) return
      t31=tm31
      t12=s*tm12
      t42=tm42
      t34=s*tm34
      return
c                                                      entry ti mtrx
      entry ti mtrx
      t41=tm41
      t32=csqi+tm32
      t14=1.0-ssqi*tm14
      t11=-si*tm11
      t44=-si*tm44
      if(iso .ne. 0) return
      t31=tm31
      t12=si*tm12
      t42=tm42
      t34=si*tm34
      return
c                                                      entry init t
      entry init t
      lht=0
      iso=0
      if(magfld .eq. 0.d0) go to 250
      if(dabs(codip-90.d0) .ge. 0.15d0)  go to 300
      if(dabs(azmuth- 90.d0) .lt. 0.15d0)  go to 250
      if(dabs(azmuth-270.d0) .ge. 0.15d0)  go to 300
  250 iso=1
  300 omega=twopi*freq*1000.d0
      ov omga=1.0/omega
      wavenr=omega/vellt
      sindip=dsin(codip*dtr)
      drcosl=sindip*dcos(azmuth*dtr)
      drcosm=sindip*dsin(azmuth*dtr)
      drcosn=-dcos(codip*dtr)
      do 60 k=1,nrspec
      coef en(k)=coeffx*1.0d6*charge(k)**2/(omega**2*ratiom(k))
      y(k)=coeffy*charge(k)*magfld/(omega*ratiom(k))
      ysq(k)=y(k)**2
      ly(k)=drcosl*y(k)
      my(k)=drcosm*y(k)
      ny(k)=drcosn*y(k)
      lsqysq(k)=drcosl**2*ysq(k)
      msqysq(k)=drcosm**2*ysq(k)
      nsqysq(k)=drcosn**2*ysq(k)
      lmysq(k)=drcosl*drcosm*ysq(k)
      lnysq(k)=drcosl*drcosn*ysq(k)
      mnysq(k)=drcosm*drcosn*ysq(k)
   60 continue
      c=cdcos(theta*dtr)
      s=cdsin(theta*dtr)
      csq=c**2
      ssq=s**2
      ci=cdcos((theta-dtheta)*dtr)
      si=cdsin((theta-dtheta)*dtr)
      csqi=ci**2
      ssqi=si**2
```

```
c
   70 t11=0.0
      t31=0.0
      t12=0.0
      t42=0.0
      t34=0.0
      t44=0.0
      return
      end
```

```
      subroutine wf bndy(b)
c
c   wf bndy computes the vector b, which determines how to combine
c   the solution vectors in order to satisfy the boundary conditions.
c   this routine is valid only for eigenangles of the modal equation
c   and is used to compute height gain functions.
c
      implicit real*8 (a-h,o-z)
      common/wf flag/precsn,iso,idbg
      common/p mtx/p(4,2),pi(16)
      common/ey grnd/eyg,hyg
      complex*16 p,b(2),r(2,2),f,rbar11,rbar22,nurmf,denmf,numa,dena,a,
     $           ex1,ex2,ey1,ey2,hx1,hx2,hy1,hy2,ey,hy,eyg,hyg,c,s,fofr,
     $           hysum,abparl,abperp
      dimension pp(16)
      data dtr/0.01745329252d0/
c
      if(idbg .gt. 1)  print 902, p
      ex1=p(1,1)
      ex2=p(1,2)
      ey1=-p(2,1)
      ey2=-p(2,2)
      hx1=p(3,1)
      hx2=p(3,2)
      hy1=p(4,1)
      hy2=p(4,2)
c
      if(iso .ne. 0)  go to 500
c   compute b, non-isotropic case (from polarization ey/hy, see budden).
      nurmf=r(2,1)*(1.0+rbar22)*rbar11
      denmf=(1.0+rbar11)*(1.0-rbar22*r(2,2))
      f of r=nurmf/denmf
      numa=-(ey1-fofr*hy1)
      dena=ey2-fofr*hy2
      a=numa/dena
      hysum=hy1+a*hy2
      b(1)=1.0/hysum*hy
      b(2)=a/hysum*hy
      eyg=(ey1*b(1)+ey2*b(2))/ey
      go to 820
c
c   compute b, isotropic case (choose correctly polarized solution).
  500 abparl=1.0-rbar11*r(1,1)
      abperp=1.0-rbar22*r(2,2)
      temp a=cdabs(abperp)
      temp b=cdabs(abparl)
      temp=temp a/temp b
      if(temp .lt. 1.0d0)  go to 600
      b(1)=1.0/hy1*hy
      b(2)=0.0
      eyg=0.0
      go to 700
  600 b(1)=0.0
      b(2)=1.0/ey2*ey
      hyg=0.0
  700 if(temp    .lt. 10.0d0)  go to 800
      if(temp    .gt.  0.1d0)  go to 800
      if(temp b .gt.  0.1d0)  go to 800
```

```
      if(temp a .gt.  0.1d0)  go to 800
      if(idbg .eq. 0)  go to 820
  800 print 900, abparl, abperp
c
  820 continue
      if(idbg.ge.2)  print 905, b
      return
c                                                    entry f fct
      entry f fct(pp,c,s,f)
      call r mtrx(pp,c,r)
      call rbars(c,s,rbar11,rbar22,ey,hy)
      if(idbg .gt. 1)  print 904, r, rbar11, rbar22
c
c   compute modal eqn. value
      a=(1.0-r(1,1)*rbar11)
      a=a*(1.0-r(2,2)*rbar22)
      f=a-r(1,2)*r(2,1)*rbar11*rbar22
      print 901,f
      return
c
  900 format('0polarization values'/
     $ ' abparl=',(1pe15.5,1pe13.5),' abperp=',(1pe15.5,1pe13.5))
  901 format('0modal eqn value=',(1pe15.5,1pe13.5))
  902 format('0p values on entry to wf bndy'/
     $        4(1pe15.5,1pe13.5)/4(1pe15.5,1pe13.5))
  904 format('0   r=',2(1pe15.5,1pe13.5)/6x,2(1pe15.5,1pe13.5)/
     $        '0rbar=',2(1pe15.5,1pe13.5))
  905 format('0solution combination factors'/
     $ ' b1=',1pe15.5,1pe13.5,'   b2=',1pe15.5,1pe13.5)
      end
```

```
      subroutine itrate
c
c  itrate is the control routine for finding an angle, theta, which
c  satisfies the modal equation.
c
      implicit real*8 (a-h,o-z)
      common/wf inpt/theta,freq,azmuth,codip,magfld,ceffnu(5),expnu(5),
     $          topht,lwstht,delht,h,alpha,sigma,epslon,nglect
      common/itrat/dtheta,bnd rl,bnd im,maxitr,itr
      common/p mtx/p(16),pi(16)
      common/cs/c,s,ci,si
      real*8 magfld,lwstht
      complex*16 theta,c,s,ci,si,dtheta,i,f,f0,dfdt,del t
      data i/(0.d0,1.d0)/
c
      nr iter=0
      if(itr .eq. 1) then
   11   call wf intg(topht,lwstht,delht,1)
        call f fct(pi,ci,si,f0)
        call f fct(p,c,s,f)
        dfdt=(f-f0)/dtheta
        del t=-f/dfdt
        theta=theta+del t
        print 900,theta
        nr iter=nr iter+1
        if(nr iter .gt. maxitr) then
          print *,'max itr exceeded'
          stop
        end if
c
        del rl=del t
        if(dabs(del rl) .gt. bnd rl) go to 11
        del im=-i*del t
        if(dabs(del im) .gt. bnd im) go to 11
      end if
c
      call wf intg(topht,lwstht,delht,0)
      call f fct(p,c,s,f)
      return
c
900   format('0new theta=',2f10.3)
      end
```

```
      subroutine p deriv(p,dpdh)
c
c  p deriv computes the height derivatives of the field vectors,
c  p, according to clemmow and heading (1954).
c  equation is dp/dz=-ik*t*p.
c  multiplication by -i is performed by operating on real and imag parts.
c  multiplication by k is performed in routine wf step.
c
      common/t mtx/t11,t31,t41,t12,t32,t42,t14,t34,t44
      complex*16 zp(4),deriv,
     $           t11,t31,t41,t12,t32,t42,t14,t34,t44
      real*8 p(8,2),dpdh(8,2),part(2)
      equivalence (deriv,part)
c
      do 11 j=1,2
      zp(1)=dcmplx(p(1,j),p(2,j))
      zp(2)=dcmplx(p(3,j),p(4,j))
      zp(3)=dcmplx(p(5,j),p(6,j))
      zp(4)=dcmplx(p(7,j),p(8,j))
      deriv=t11*zp(1)+t12*zp(2)+t14*zp(4)
      dpdh(1,j)= part(2)
      dpdh(2,j)=-part(1)
      deriv=zp(3)
      dpdh(3,j)= part(2)
      dpdh(4,j)=-part(1)
      deriv=t31*zp(1)+t32*zp(2)+t34*zp(4)
      dpdh(5,j)= part(2)
      dpdh(6,j)=-part(1)
      deriv=t41*zp(1)+t42*zp(2)+t44*zp(4)
      dpdh(7,j)= part(2)
   11 dpdh(8,j)=-part(1)
      return
      end
```

```
      function cdang(arg)
      implicit real*8 (a-h,o-z)
      complex*16 arg,mi/(0.d0,-1.d0)/
c
      argr=arg
      argi=arg*mi
      cdang=datan2(argi,argr)
      return
      end
```

# APPENDIX B

## SOURCE LISTING FOR PROGRAM WFPLTS

## A BRIEF DESCRIPTION OF USAGE OF PROGRAM WFPLTS

If the namelist logical variable SAVPLT is equal to .TRUE. (which is the default value), data are written to unit 10 for optional further processing and plotting by the program WFPLTS. WFPLTS has two sources of input: the data file generated by WAVFLD and namelist input. The program prompts the user for the name of the WAVFLD data file and then asks for the namelist data. There are four variables in the namelist: the size of the x-axis, the size of the y-axis in inches, a scaling factor and a plotting flag. The plotting flag is NPLOT, an array of six integers. It controls which plots are generated. A maximum of six plots may be generated.

If NPLOT(1) is non-zero Q and ATTEN are plotted.

If NPLOT(2) is non-zero the magnitude of SX, SY and SZ are plotted.

If NPLOT(3) is non-zero angles between SX and SZ, SY and SZ, B DOT S are plotted.

If NPLOT(4) is non-zero X, Y, and Z are plotted.

If NPLOT(5) is non-zero the magnitude of EX, EY, and EZ are plotted.

If NPLOT(6) is non-zero the magnitude of HX, HY, and HZ are plotted.

When the program prompts the user for the namelist input, default values for all variables are listed, so only variables the user wishes to change need be entered.

```
c      program to plot output file from wavfld
c
c      nplot controls groups of plots:
c      nplot(1) ne 0 gives q and atten
c            2              magnitude of sx, sy and sz
c            3              angles between sx and sz, sy and sz, b dot s
c            4              x, y and z
c            5              magnitude of ex, ey and ez
c            6              magnitude of hx, hy and hz
c
       dimension plotx(101,16),ploty(101),up(101),xl(2),yl(2),ul(2),
      $          nplot(6),idate(3),itime(2),ilabel(15),ibcd(20)
       character*60 pltlbl
       character*40 bcd
       logical up,ul
c
       namelist/datum/sizex,sizey,scalex,plot
c
       data nplot/1,2,4*0/,sizex,sizey,  4.,  5.,  scalex/2.,
      $     up/101*.false./,xl/0.,1./,yl/ 1*0.,1./,ul/2*.true./
c
       equivalence (ilabel,plt
c
       print *,'Enter
       accept 1000,b
       open(unit=10,
c
       print *,'Enter
       read datum
c
c      begin plot
c
90     read(10,end=999)
      $
c
       ymax=aint(htmax 10.+.99)*10.
       ymin=aint(htmin 10.)*10.
       yscale=(ymax-ymin)/sizey
c
       do 299 mplot=1,6
       if(nplot(mplot) .eq. 0)
       call pltbgn
c
       call symbol(0.0,0.0,0.1,'wavfld',0.,6
       call symbol(1.0,0.0,0.1,idate,0.,12)
       call symbol(2.5,0.0,0.1,itime,0.,8)
       call plot(.5,1.,-3)
       xp=0.0
       yp=-.4
       call symbol(xp,yp,.1,ibcd ,0.,68)
       encode(60,2000,pltlbl) frq,rho,azm,cdp,sig
       yp=yp-.2
       call symbol(xp,yp,.1,ilabel,0.,60)
       yp=yp-0.2
       go to (100,103,106,110,115,120),mplot
c
100    amax=-1000.
       do 101 i=1,nrht
```

```
      plotx(j,2)=alog10(amax1(1.e-10,attn-plotx(j,2)))
      do 101 k=1,2
101   if(amax .lt. plotx(j,k)) amax=plotx(j,k)
      xmax=aint(amax/scalex+.99)*scalex
      xmin=xmax-sizex*scalex
      xscale=scalex
      call border(sizex,xmin,xmax,xscale,1, sizey,ymin,ymax,10.,1)
c
      do 102 j=1,nrht
      do 102 k=1,2
102   if(plotx(j,k) .lt. xmin) plotx(j,k)=xmin
      call symbol(xp,yp,.1,' q',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,1)
      xp=xp+1.2
      call curve(plotx(1,1),ploty,up,nrht,xmin,ymin,xscale,yscale,1)
      call newpen(2)
      call symbol(xp,yp,.1,'at',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,4)
      xp=xp+1.2
      call curve(plotx(1,2),ploty,up,nrht,xmin,ymin,xscale,yscale,4)
      go to 298
c
103   amax=-1000.
      do 104 j=1,nrht
      do 104 k=3,5
104   if(amax .lt. plotx(j,k)) amax=plotx(j,k)
      xmax=aint(amax/scalex+.99)*scalex
      xmin=xmax-sizex*scalex
      xscale=scalex
      call border(sizex,xmin,xmax,xscale,1, sizey,ymin,ymax,10.,1)
c
      do 105 j=1,nrht
      do 105 k=3,5
105   if(plotx(j,k) .lt. xmin) plotx(j,k)=xmin
      call symbol(xp,yp,.1,'sx',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,1)
      xp=xp+1.2
      call curve(plotx(1,3),ploty,up,nrht,xmin,ymin,xscale,yscale,1)
      call newpen(2)
      call symbol(xp,yp,.1,'sy',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,2)
      xp=xp+1.2
      call curve(plotx(1,4),ploty,up,nrht,xmin,ymin,xscale,yscale,2)
      call newpen(3)
      call symbol(xp,yp,.1,'sz',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,4)
      xp=xp+1.2
      call curve(plotx(1,5),ploty,up,nrht,xmin,ymin,xscale,yscale,4)
      go to 298
c
106   xmin=-180.
      xmax= 180.
      xscale=360./sizex
```

```
      call border(sizex,xmin,xmax,xscale,1, sizey,ymin,ymax,10.,1)
      call symbol(xp,yp,.1,'atan(sz/sx)',0.,11)
      xp=xp+1.15
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,1)
      xp=xp+1.2
      call curve(plotx(1,6),ploty,up,nrht,xmin,ymin,xscale,yscale,1)
      call newpen(2)
      call symbol(xp,yp,.1,'atan(sz/sy)',0.,11)
      xp=xp+1.15
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,2)
      xp=xp+1.2
      call curve(plotx(1,7),ploty,up,nrht,xmin,ymin,xscale,yscale,2)
      call newpen(3)
      call symbol(xp,yp,.1,'acos(b . s)',0.,11)
      xp=xp+1.15
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,4)
      xp=xp+1.2
      call curve(plotx(1,8),ploty,up,nrht,xmin,ymin,xscale,yscale,4)
      go to 298
C
110   amax=-1000.
      do 111 j=1,nrht
      do 111 k=9,10
111   if(amax .lt. plotx(j,k)) amax=plotx(j,k)
      xmax=aint(amax/scalex+.99)*scalex
      xmin=xmax-sizex*scalex
      xscale=scalex
      call border(sizex,xmin,xmax,xscale,1, sizey,ymin,ymax,10.,1)
      do 112 j=1,nrht
      do 112 k=9,10
112   if(plotx(j,k) .lt. xmin) plotx(j,k)=xmin
      call symbol(xp,yp,.1,'x',0.,1)
      xp=xp+0.15
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,5)
      xp=xp+1.2
      call curve(plotx(1, 9),ploty,up,nrht,xmin,ymin,xscale,yscale,5)
      call newpen(2)
      call symbol(xp,yp,.1,'z',0.,1)
      xp=xp+0.15
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,3)
      xp=xp+1.2
      call curve(plotx(1,10),ploty,up,nrht,xmin,ymin,xscale,yscale,3)
      call newpen(3)
      call symbol(xp,yp,.1,'y',0.,1)
      xp=xp+0.15
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,1)
      xp=(alog10(capy)-xmin)/xscale
      if(xp .le.    0.) go to 298
      if(xp .ge. sizex) go to 298
      call plot(xp,   0.,3)
      call plot(xp,sizey,2)
      go to 298
C
115   amax=-1000.
      do 116 j=1,nrht
      do 116 k=11,13
116   if(amax .lt. plotx(j,k)) amax=plotx(j,k)
      xmax=aint(amax/scalex+.99)*scalex
```

```
      xmin=xmax-sizex*scalex
      xscale=scalex
      call border(sizex,xmin,xmax,xscale,1, sizey,ymin,ymax,10.,1)
      do 117 j=1,nrht
      do 117 k=11,13
117   if(plotx(j,k) .lt. xmin) plotx(j,k)=xmin
      call symbol(xp,yp,.1,'ex',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,1)
      xp=xp+1.2
      call curve(plotx(1,11),ploty,up,nrht,xmin,ymin,xscale,yscale,1)
      call newpen(2)
      call symbol(xp,yp,.1,'ey',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,3)
      xp=xp+1.2
      call curve(plotx(1,12),ploty,up,nrht,xmin,ymin,xscale,yscale,3)
      call newpen(3)
      call symbol(xp,yp,.1,'ez',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,4)
      xp=xp+1.2
      call curve(plotx(1,13),ploty,up,nrht,xmin,ymin,xscale,yscale,4)
      go to 298
c
120   amax=-1000.
      do 121 j=1,nrht
      do 121 k=14,16
121   if(amax .lt. plotx(j,k)) amax=plotx(j,k)
      xmax=aint(amax/scalex+.99)*scalex
      xmin=xmax-sizex*scalex
      xscale=scalex
      call border(sizex,xmin,xmax,xscale,1, sizey,ymin,ymax,10.,1)
      do 122 j=1,nrht
      do 122 k=14,16
122   if(plotx(j,k) .lt. xmin) plotx(j,k)=xmin
      call symbol(xp,yp,.1,'hx',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,1)
      xp=xp+1.2
      call curve(plotx(1,14),ploty,up,nrht,xmin,ymin,xscale,yscale,1)
      call newpen(2)
      call symbol(xp,yp,.1,'hy',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,3)
      xp=xp+1.2
      call curve(plotx(1,15),ploty,up,nrht,xmin,ymin,xscale,yscale,3)
      call newpen(3)
      call symbol(xp,yp,.1,'hz',0.,2)
      xp=xp+0.25
      call curve(xl,yl,ul,2,-xp,-yp,1.,1.,4)
      xp=xp+1.2
      call curve(plotx(1,16),ploty,up,nrht,xmin,ymin,xscale,yscale,4)
c
298   call pltend
299   continue
      go to 90
c
```

```
999   stop
1000  format(a40)
2000  format('f=',f7.3,' r=',f7.3,' a=',f7.3,' c=',f7.3,' s=',1pe7.1)
      end
```

```
      subroutine curve(x,y,up,nrpts,xmin,ymin,xinc,yinc,line)
c
c x,y,up must be dimensioned at least nrpts
c xmin,ymin are x,y origin in user units
c xinc,yinc are x,y scales in user units per inch
c
c line=1:  solid
c      2:  long dash
c      3:  medium dash
c      4:  short dash
c      5:  dotted
c      6:  short + long dash
c      7:  short + short + long dash
c
      logical up,up1,up2
      dimension ipen(10),joc(7),x(nrpts),y(nrpts),up(nrpts)
      data ipen/3,2,3,2,3,2,2,2,2,2/,joc/18, 61, 56, 54, 52, 11, 36/
      data delr/.1/
c
      if(nrpts .le. 1) go to 99
c
      if(line) 1,2,3
1     kk=mod(line,7)+7
      go to 4
2     kk=0
      go to 4
3     kk=mod(line,7)
4     kk=kk+1
      jo=joc(kk)/10
      jc=joc(kk)-10*jo
c
      j=1
      ip=2
      if(kk .eq. 6) ip=3
      dr=0.
      rho1=0.
      rho2=delr
      px1=(x(1)-xmin)/xinc
      py1=(y(1)-ymin)/yinc
      up1=up(1)
      if(up1) go to 10
c
c go to first position with pen up
      call plot(px1,py1,3)
c
10    do 40 i=2,nrpts
      px2=(x(i)-xmin)/xinc
      py2=(y(i)-ymin)/yinc
      up2=up(i)
      if(up2) go to 22
      if(up1) go to 37
      if(kk .eq. 2) go to 38
      delx=px2-px1
      dely=py2-py1
      rho=sqrt(delx**2+dely**2)
      rho1=rho1+rho
      if(rho2 .gt. rho1) go to 38
      delx=delx*delr/rho
```

```
      dely=dely*delr/rho
      dx 6=delx*.1
      dy 6=dely*.1
      if(dr .eq. 0.) go to 20
      dx=delx*dr/delr
      dy=dely*dr/delr
      pxl=pxl+dx
      pyl=pyl+dy
      go to 21
20    if(rho2 .gt. rhol) go to 38
      pxl=pxl+delx
      pyl=pyl+dely
21    call plot(pxl,pyl,ip)
      if(kk .eq. 6) call plot(pxl+dx6,pyl+dy6,2)
      j=j+1
      ip=ipen(jo+mod(j,jc))
      rho2=rho2+delr
      go to 20
22    dr=0.
      rhol=0.
      rho2=delr
      go to 39
c pen has been up, prepare to lower pen
37    call plot(px2,py2,3)
      go to 39
38    call plot(px2,py2,ip)
      dr=rho2-rhol
39    pxl=px2
      pyl=py2
      upl=up2
40    continue
99    return
      end
```

```
      subroutine border(xlng,xmin,xmax,xinc,nx,ylng,ymin,ymax,yinc,ny)
c
      dimension xinc(nx),yinc(ny)
      logical fy,fx
c
      fx=.false.
      fy=.false.
      if(nx .eq. 1) fx=.true.
      if(ny .eq. 1) fy=.true.
      xt=xlng-.1
      yt=ylng-.1
      xscale=xlng/(xmax-xmin)
      yscale=ylng/(ymax-ymin)
      ym=abs(ymin)
      yln=-.4
      if(ym .ge. 10.) yln=yln-.1
      if(ym .ge. 100.) yln=yln-.1
      if(ym .ge. 1000.) yln=yln-.1
      if(ymin .lt. 0.) yln=yln-.1
      ym=abs(ymax)
      ylm=-.4
      if(ym .ge. 10.) ylm=ylm-.1
      if(ym .ge. 100.) ylm=ylm-.1
      if(ym .ge. 1000.) ylm=ylm-.1
      if(ymax .lt. 0.) ylm=ylm-.1
      xm=abs(xmax)
      xlm=-.3
      if(xm .ge. 10.) xlm=xlm-.1
      if(xm .ge. 100.) xlm=xlm-.1
      if(xm .ge. 1000.) xlm=xlm-.1
      if(xmax .lt. 0.) xlm=xlm-.1
      if(fx) dx=xinc(1)
      if(fy) dy=yinc(1)
      iy=1
      yl=0.
      call number(yln,0.,.1,ymin,0.,1)
      call plot(0.,0.,3)
      if(fy) go to 110
10    yp=(yinc(iy)-ymin)*yscale
      go to 111
110   yl=yl+dy
      yp=yl*yscale
111   if(yp .lt.   0.) go to 99
      if(yp .ge. ylng) go to 11
      call plot(0.,yp,2)
      call plot(.1,yp,2)
      call plot(0.,yp,2)
      if(fy) go to 110
      iy=iy+1
      if(iy .le. ny) go to 10
11    call plot(0.,ylng,2)
      call number(ylm,ylng-.1,.1,ymax,0.,1)
      call plot(0.,ylng,3)
      ix=1
      xl=0.
      if(fx) go to 112
12    xp=(xinc(ix)-xmin)*xscale
      go to 120
```

```
112   xl=xl+dx
      xp=xl*xscale
120   if(xp .lt.   0.) go to 99
      if(xp .ge. xlng) go to 13
      call plot(xp,ylng,2)
      call plot(xp,yt,2)
      call plot(xp,ylng,2)
      if(fx) go to 112
      ix=ix+1
      if(ix .le. nx) go to 12
13    call plot(xlng,ylng,2)
      if(fy) go to 130
113   iy=iy-1
      if(iy .le. 0) go to 15
      yp=(yinc(iy)-ymin)*yscale
      go to 14
130   yl=yl-dy
      yp=yl*yscale
      if(yp .le. 0.) go to 15
14    call plot(xlng,yp,2)
      call plot(xt,yp,2)
      call plot(xlng,yp,2)
      if(fy) go to 130
      go to 113
15    call plot(xlng,0.,2)
      call number(xlng+xlm,-.2,.1,xmax,0.,1)
      call plot(xlng,0.,3)
      if(fx) go to 150
115   ix=ix-1
      if(ix .le. 0) go to 17
      xp=(xinc(ix)-xmin)*xscale
      go to 16
150   xl=xl-dx
      xp=xl*xscale
      if(xp .le. 0.) go to 17
16    call plot(xp,0.,2)
      call plot(xp,.1,2)
      call plot(xp,0.,2)
      if(fx) go to 150
      go to 115
17    call plot(0.,0.,2)
      call number(0.,-.2,.1,xmin,0.,1)
      return
99    print 100,xlng,xmin,xmax,xinc(1),nx,ylng,ymin,ymax,yinc(1),ny
100   format('0***  Error in BORDER:  xlng, xmin, xmax, xinc(1), nx =',
     $       1p4e15.5,i5/24x,'ylng, ymin, ymax, yinc(1), ny =',1p4e15.5,
     $       i5/'0***')
      call pltend
      stop
      end
```

END

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