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Computer Programs for Assessment of Long-Wavelength Radio Communications, Version 2.0

User's Guide and Source Files

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INTRODUCTION

This document describes a revision of the Navy's Long-Wavelength Propagation Capability (LWPC) developed by the Space and Naval Warfare Systems Center, San Diego. Ferguson and Snyder (1989a,b; 1990) and Ferguson (1990; 1993) documented previous versions of this capability. This document describes a revision of the LWPC, designated version 2.0 (LWPC–2.0), that includes improvements to the graphics routines, increased flexibility in specification of alternative iono- spheric models, and an option to execute a full-wave mode-conversion model for the signal-strength calculations. This version is principally composed of FORTRAN subroutines with a few additional routines written in C to implement the graphics capabilities under the Windows 95/NT operating systems. The LWPC is a collection of separate programs that perform unique actions. For example, the program that implements the propagation model and associated calculations is named the Long- Wave Propagation Model (LWPM), and the program that generates geographical displays of the signal strength is named GRDPLOT. These individual programs are described below.

The LWPC is typically used to generate geographical maps of signal availability for coverage analysis. The program makes it easy to set up these displays by automating most of the required steps. The user specifies the transmitter location and frequency, the orientation of the transmitting and receiving antennae, and the boundaries of the operating area. The program automatically selects paths along geographic bearing angles to ensure that the operating area is fully covered. The diurnal conditions and other relevant geophysical parameters are then determined along each path. After the mode parameters along each path are determined, the signal strength along each path is computed. The signal strength along the paths is then interpolated onto a grid overlying the operating area. The final grid of signal strength values is used to display the signal-strength in a geographic display.

The LWPC uses character strings to control programs and to specify options. The control strings have the same meaning and use among all the programs. On input, most control strings may be abbreviated. For example, the string **TX-DATA** can be entered in upper or lower case and can be shortened to **TX-D.** If a control string is shortened too much, it will not be recognized and execution will stop. To make it easier to read control strings composed of more than one word, dashes or underscores are used to connect the separate words, as in the above example. A blank in the first col- umn of a line of data causes the string to be treated as a comment line, allowing the user to annotate run streams for documentation and to provide prompts for editing. This feature also makes it con- venient to switch various program options on and off.

This document is primarily a description of a computer program. It is difficult to distinguish the names of programs, variables, file names, etc., from each other. In this document, such difficulties are compounded by the use of control strings that are strings of characters used to organize the many different kinds of input to the program and to direct the order and types of calculations to be per- formed. Furthermore, some of the input parameters represent strings of characters while others represent numerical values. The following conventions will be used in this document:

Names of programs	Uppercase, i.e., LWPM
Names of files	Uppercase in double quotes, i.e., "SAMPLE.MDS"
Control strings	Uppercase, bold, i.e., **TX-DATA**
Character strings	Uppercase, italics, i.e., *TX-IDENTIFICATION*
Numerical inputs	Italics, i.e., *frequency*

SUMMARY OF MODIFICATIONS

New control string handlers have been written that allow parameter lists for control strings to be truncated. New graphics routines were written to enhance the graphical interface and to use operating-system printer drivers. A new graphics initialization file was added to enable user-specified color and fill schemes. Filled contour plotting was implemented. The option of exporting the graphical output to PowerPoint was added. High-resolution maps of landmasses and coastal outlines were developed. Orthographic and stereographic map displays were added. The variability of the signal as stored in the "GRD" files was modified to use separate values for day, night, and transition. The handling of atmospheric noise statistics was modified to include the noise variability parameters, D_u and σ_u, making the coverage predictions consistent with CCIR (1963) recommendations. Two models of receiver performance with respect to atmospheric noise were added. These changes also make the predictions more conservative. An option for user-specified path segmentation was added.

PROPAGATION MODEL

The propagation model implemented in the LWPC treats the space between the earth's surface and the lower ionosphere as a waveguide. The upper boundary of this waveguide is the earth's ionosphere that is characterized by a conductivity that may be specified by the user. A number of possible specifications of the ionosphere are provided in the LWPM ranging from a simple, horizontally homogeneous exponential conductivity profile to complicated spatially varying distributions of electron and charged-ion densities. It should be noted that many of the parameters that describe the boundaries of the earth-ionosphere waveguide are not known with great accuracy over all regions and times.

The default model of the ionosphere used in the LWPM employs a conductivity that increases exponentially with height. A log-linear slope and a reference height define this exponential model. The default model defines an average value of the slope and reference height that depends on frequency and diurnal condition. Furthermore, the height of the nighttime ionosphere over the polar caps is lower than it is at middle and equatorial latitudes. This model was derived from extensive analysis of available measurements as described by Ferguson (1980, 1992) and Morfitt (1977). The default model of the lower boundary of the waveguide is based on the Westinghouse Geophysics Laboratory conductivity map (Morgan, 1968).

Propagation paths are broken into a series of horizontally homogeneous segments. The distribution and the parameters of the segments are determined by changes in the ionosphere, ground conductivity, and the geomagnetic field. The LWPM uses two procedures to calculate the mode solutions for each horizontally homogeneous segment. Segments with a common ground conductivity and ionosphere are grouped together and processed in order of increasing distance from the transmitter. At the beginning of each of these groups, a mode-searching algorithm is used to obtain starting solutions. This algorithm is essentially that of Morfitt and Shellman (1979). The mode solutions in the remaining segments of a particular group are obtained by extrapolating up to three sets of existing solutions by using distance from the transmitter as the extrapolation variable. The extrapolated solutions are adjusted for the effects of the geomagnetic field by using a Newton–Raphson iteration technique. If the distance over which the extrapolation is performed is too large, or the extrapolation or the iteration gives invalid modes, the modes of the segment are found by using the mode-searching algorithm. The extrapolation and iteration procedure is then restarted. This combination of rigorous mode

searching and extrapolation followed by iterative correction gives the most efficient generation of the required mode parameters along the propagation path.

The LWPC uses a mode-conversion model (Ferguson and Snyder, 1980) to connect the series of horizontally homogenous segments along every propagation path. The most accurate implementation of the mode-conversion model integrates the radio fields vertically over the boundary between segments. This integration can be quite time consuming. A reasonably accurate and much faster running implementation replaces the full-wave integration with an approximation based on the notion that most of the interaction of the radio wave takes place within the reflection height of the ionosphere. The default implementation of the mode-conversion model is the approximate one. In rare cases, the full-wave model must be employed to ensure accuracy. Unfortunately, there is no test that can be performed ahead of time to ensure that this option is necessary. The user must review the output of the program, particularly graphs of the signal strength *versus* distance, to ensure that they make sense. Generally, the need to use the full-wave model is readily apparent in these graphs.

The LWPC is typically used to generate geographical maps of signal availability for coverage analysis. The program makes it easy to set up these displays by automating most of the required steps. The program automatically selects paths along geographic bearing angles at a coarse resolution of 15° to ensure that the operating area is fully covered. More paths are added as necessary, at a finer resolution of 3°, to ensure that all significant low-conductivity areas of the ground are included in the coverage analysis. Figure 1 illustrates this automatic path selection for a transmitter located in North Dakota and an operating area that encloses the Mediterranean Sea. In the color rendition of this map, the areas shown in yellow, black, red, and purple are regions of low ground conductivity. In this figure, these areas are found in eastern Canada and Greenland. The figure shows the boundary of the operations area and all of the propagation paths automatically selected by the LWPM. Three of the paths are shown as solid lines. These are the ones from the pass using coarse resolution (30°, 45°, and 60°). The dashed lines show the paths selected during the second pass. These are required to ensure that the low-conductivity areas are included in the coverage.
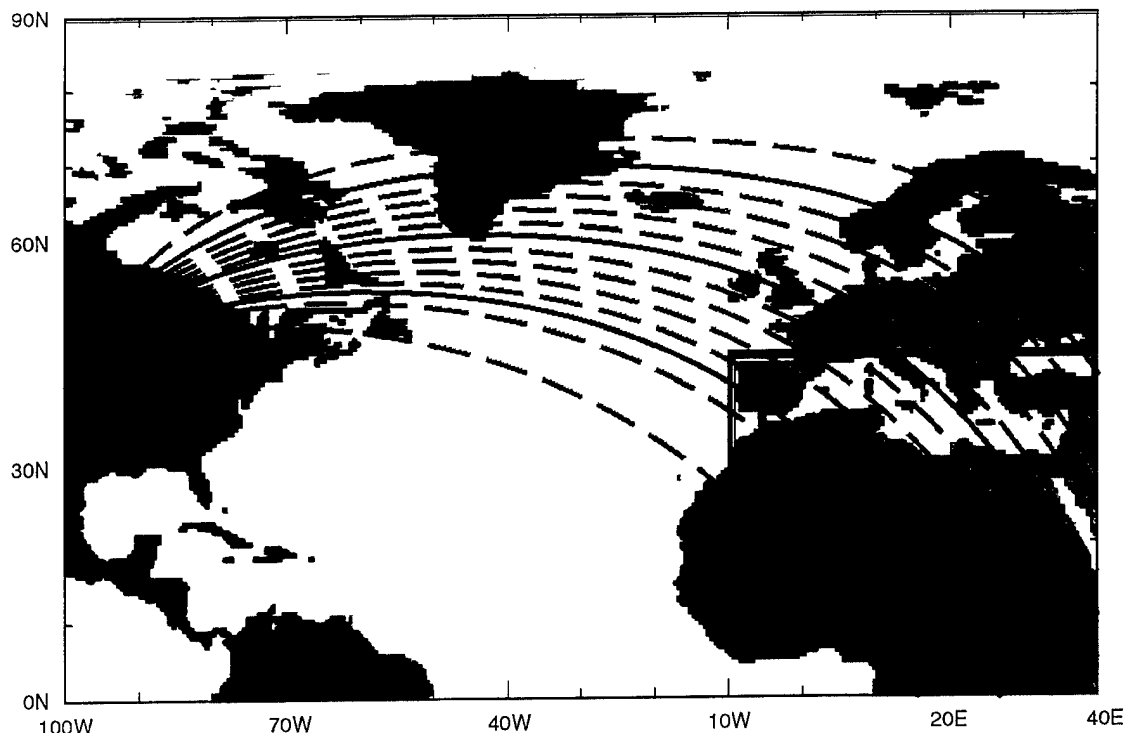
Figure 1. Illustration of automatic path selection.

GEOPHYSICAL MODEL

As already noted, a waveguide model is used for propagation in the LWPM. The boundaries of this waveguide are the earth's surface and the ionosphere. The lower boundary is considered to be a set of semi-infinite regions of fixed conductivity extending downward from the surface. The parameters of the upper boundary vary depending primarily on solar radiation. The electron density and the earth's geomagnetic field control the interaction of the radio waves with the ionosphere. The effect of the geomagnetic field is small in the daytime and significant in the nighttime.

THE IONOSPHERE

There are two major transitions in the ionosphere. One of these transitions is between daytime and nighttime. The other transition occurs in the nighttime between middle geomagnetic latitudes and polar latitudes. The nighttime ionosphere in the polar latitudes is strongly influenced by injections of solar particles guided there by the earth's geomagnetic field. In the simple model of the ionosphere used in the LWPM, the effect of these particles is to lower the effective height of the ionosphere. The solar zenith angle is the key parameter used to determine the ionospheric profile at each point along the path. The daytime ionosphere is specified for solar zenith angles less than $90°$ and the nighttime ionosphere for solar zenith angles greater than $99°$. For nighttime paths, the geomagnetic dip angle determines the geomagnetic latitude. The nighttime latitudinal transition from middle to polar latitudes takes place between geomagnetic dip angles of $70°$ and $74°$.

The model of the ionosphere used in the LWPM produces an exponential increase in conductivity with height specified by a slope, β, in km^{-1} and a reference height, h', in km. Values for β and h' are

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specified by the program for both daytime and nighttime at each of two reference frequencies. Given the frequency specified by the user, values of β and h' for day and for night are obtained by linear interpolation in frequency. Between the daytime and nighttime values of β and h', five additional values of β and h' are calculated at equal intervals. Figure 2 illustrates how these five intervals define the basic dawn/dusk transition.
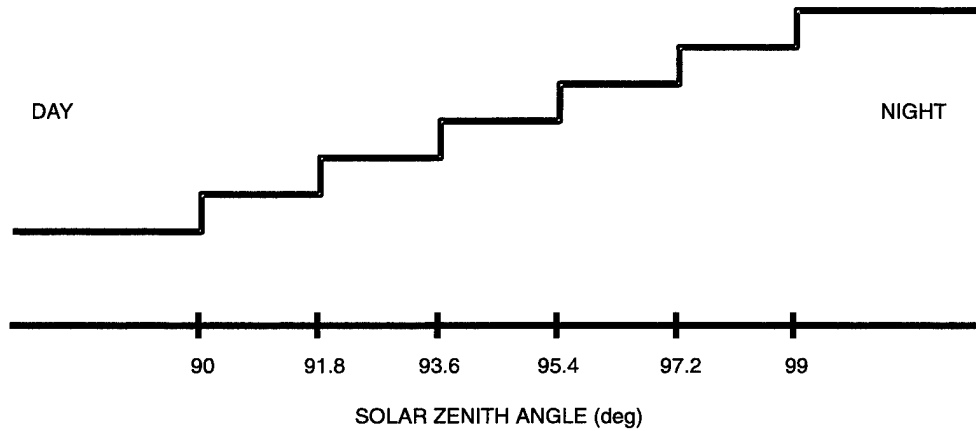
Figure 2. Illustration of the day/night transition.

When the path is fully night, h' also depends on the geomagnetic dip angle. This dependence is chosen so that the h' for the polar nighttime ionosphere is the midpoint of the intervals between day and night. Thus, the last four segments of the day-to-night transition are used to make the transition from middle latitudes to polar latitudes when the propagation path is in night. However, the magnetic dip angle, rather than the solar zenith angle, controls the ionosphere. Figure 3 illustrates this transition. This simple model is used to provide a reasonable set of ionospheric profiles to handle all the transitions in the ionosphere. A more sophisticated model is not warranted because of a lack of data.
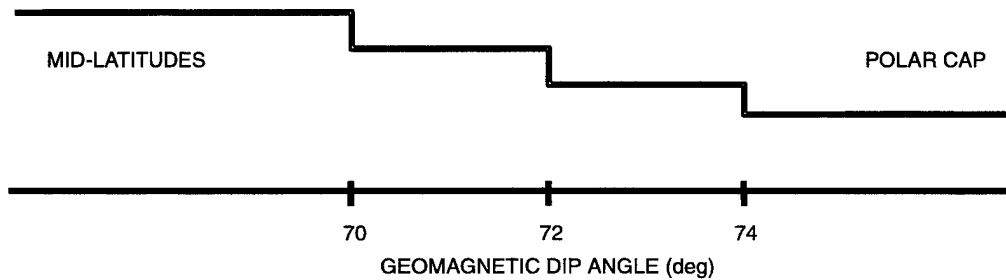
Figure 3. Illustration of the polar cap transition.

The numerical specification of the model of the ionosphere used in this program is derived from Morfitt (1977) and Ferguson (1980) and is the same as in previous versions of the LWPC (Ferguson and Snyder, 1989b). This model sets the value of β and h' for the daytime and nighttime ionosphere separately. The daytime ionosphere has a constant value of β equal to 0.3 km^{-1} and a constant value of h' equal to 74 km. The nighttime ionosphere is more complicated in that β varies with frequency while h' is constant at 87 km. The variation with frequency has β varying from 0.3 km^{-1} at 10 kHz to 0.8 km^{-1} at 60 kHz. Table 1 shows the values of the ionospheric parameters at 30 kHz. Figure 4 illustrates the two transitions, as they would be defined along a hypothetical path that traverses the pole from day to night using the parameters in this table.

Table 1. Transition parameters.

Solar Zenith Angle (χ) (deg)			b (km^{-1})	h' (km)	Geomagnetic Dip (D) (deg)			
	χ < 90	Day	0.30	74.0			D < 70	
90 < χ < 91.8			0.33	76.2	70	< D <	72	
91.8 < χ < 93.6			0.37	78.3	72	< D <	74	
93.6 < χ < 95.4			0.40	80.5	74	< D <	90	Pole
95.4 < χ < 97.2			0.43	82.7	72	< D <	74	
97.2 < χ < 99			0.47	84.8	70	< D <	72	
99 < χ		Night	0.50	87.0			D < 70	

Although not shown in table 1 and figures 2 through 4, the LWPM uses solar zenith angles in a way that indicates whether the direction of propagation is from midnight toward noon or *vice versa*. Thus, for every set of ranges on the left side of table 1, there is a mirrored set of negative values of solar zenith angles. The current implementation of the LWPM treats the transition from midnight to noon the same as that from noon to midnight.
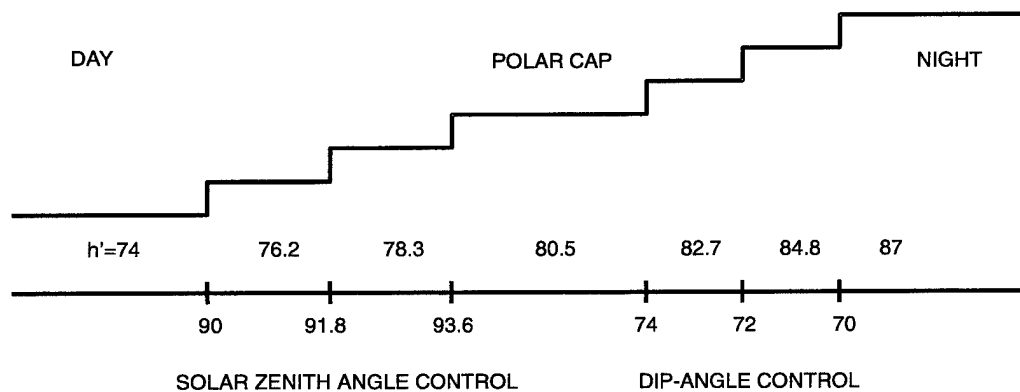
Figure 4. Illustration of the transpolar transition.

PATH SEGMENTATION

Geometrically, a propagation path is a great circle from the transmitter. The LWPM models the variation of the geophysical parameters along the path as a series of horizontally homogeneous segments. To do this, the program determines the ground conductivity, dielectric constant, orientation of the geomagnetic field with respect to the path and the solar zenith angle at small fixed-distance intervals along each path. At each of the small intervals, these parameters are examined to determine if a new segment of the earth-ionosphere waveguide needs to be set. The goal of this process is to include important features of the propagation path while keeping the number of segments to a computationally manageable level. An additional consideration is the balancing of the completeness of the mode-searching algorithm with the speed of the extrapolation and iteration algorithm as it processes many segments. Figure 5 illustrates the decision-making process. It accounts in large part for the differences in how the waveguide-mode solutions vary under differing ionospheric conditions and from one geomagnetic condition to another. For example, propagation anisotropy is considerably

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diminished under day conditions as compared to nighttime conditions. Therefore, the variation of the geomagnetic parameters between points on the path is allowed to be larger in daytime than at night. In figure 5, the appearance of "SAVE" indicates that a horizontally homogenous path segment will be defined and mode parameters will be computed for that segment. It should be noted that the minimum length of a segment is 100 km.

If (R = 0) then SAVE
If (σ or h' changed and δR > 100 km) then SAVE
If (IDI > 80) then NEXT R
If (h' > h'$_{polar}$) then ──────────────

Day-like
If (δD > 15) then SAVE
If (70 < IDI < 80 and A > 45) then SAVE
If (30 < IDI < 70 and A > 30) then SAVE
If (0 < IDI < 30 and A > 15) then SAVE

Next R

Night-like
If (δD > 10) then SAVE
If (70 < IDI < 80 and A > 20) then SAVE
If (30 < IDI < 70 and A > 15) then SAVE
If (0 < IDI < 30) then ──────

Next R

Trans-Equatorial
If (170 < A < 210 and δD > 3) then SAVE
If (350 < A < 30 and δD > 3) then SAVE
If (δA > 15) then SAVE

Next R

Legend

R   Distance from the transmitter
δR   Change in R since the last SAVE
D   Geomagnetic dip angle
δD   Change in D since the last SAVE
A   Geomagnetic azimuth angle
δA   Change in A since the last SAVE
h'   Reference height of the ionosphere
σ   Ground conductivity

Figure 5. Flow diagram for path segmentation.

ATMOSPHERIC NOISE

The LWPC allows for three models of atmospheric noise. The model named *ITSN* is the implementation of CCIR 322 (CCIR, 1963), which maps the basic noise map parameter, F_{am}, in Universal time. The model named *NTIA* is the new noise model developed by using additional measurements and has since become the new CCIR model described in CCIR Report 322–3 (CCIR, 1986). These two models are based on surface mappings of measurements at a limited number of sites. The model named *LNP* is a lightning-based model developed by Pacific Sierra Research for the Office of Naval Research and the Defense Nuclear Agency (Warber and Shearer, 1994). This model calculates atmospheric noise by summing the contributions from lightning all over the world after calculating the effects of propagation from the lightning to the receiver. Thus, it is computationally quite complicated and slow running.

The nature of atmospheric noise can have a dramatic effect on the performance of radio receivers. Receivers are designed with algorithms designed to minimize the most important detrimental effects of atmospheric noise. However, the key to understanding how the receivers will perform in different locations and times is proper modeling of the critical parameters of atmospheric noise. Typically, these parameters are the mean value, the standard deviation of the variation, and the impulsiveness of the noise. The latter is described by the ratio of the rms to the average of the noise expressed in dB, which is called the V_d. The variation of these parameters of atmospheric noise over time and position is quite different among these models, so the coverage assessments produced simply by changing the model of atmospheric noise can be spectacular.

RECEIVER MODEL

Two models of receiver performance have been incorporated into the LWPC. One of these is described by Buckner and Daghestani (1993) and designated as *PSR*, and the other is described by Smith et al. (1997) and designated as *MITRE*. The curves in figure 6 illustrate the relative gain in the noise-reduction circuit (NRC) as a function of the noise parameter, V_d. The *PSR* model (dashed line) shows significant gains for V_d greater than 12 dB but equally significant reductions in performance when V_d is less than 7 dB. On the other hand, the *MITRE* model (solid line) produces a much more conservative picture of receiver performance with regard to the impulsiveness of the atmospheric noise.
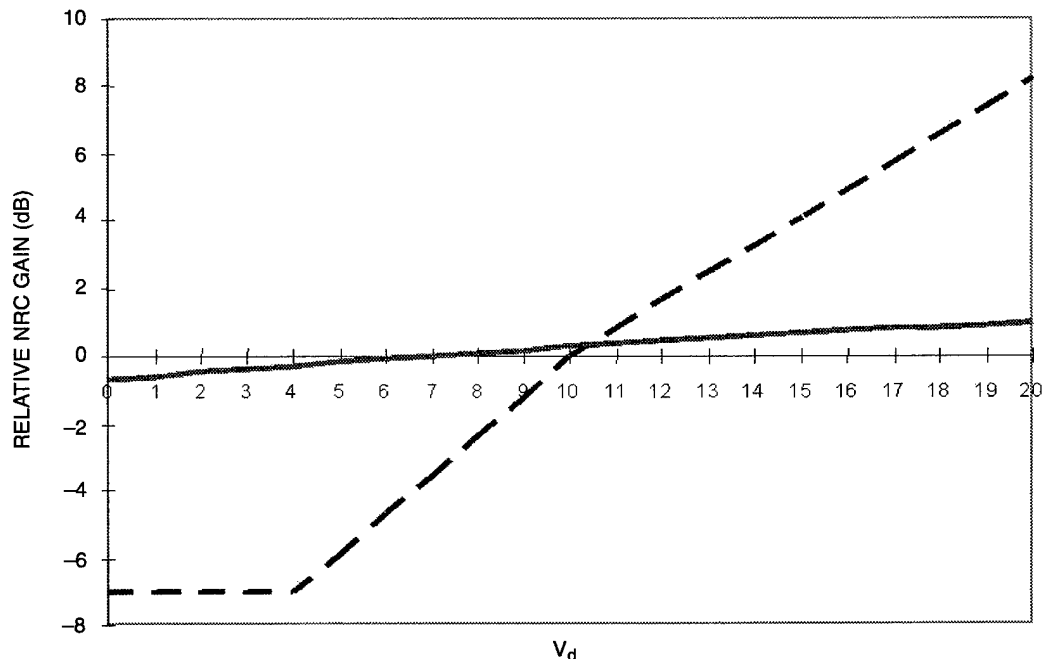
Figure 6. Comparison between PSR and MITRE receiver models.

DRIVER PROGRAM

The program named LWPM sets up propagation paths and organizes the calculation of solutions to the earth-ionosphere waveguide (mode parameters). Basic input to the program consists of a root file name (used to define the names of output files), transmitter parameters, and the diurnal condition. The basic transmitter parameters consist of its location and frequency. The diurnal condition may be specified as all day, all night, or as a specific date and time. The propagation paths can be defined by specifying geographical bearing angles, receiver locations, or an operating area. These control strings are placed in files with the extension "INP" (for Inputs).

After the necessary control strings and their associated data are specified, a specific control string is used to initiate the calculations. As the calculation of mode parameters along each path is completed, the parameters are written to a file named with the extension "MDS" (for Modes). Calculations for successive paths continue automatically. If the generation of the data aborts for some reason, the user needs to correct the error (if any) and restart the program. If it exists, the LWPM reads the "MDS" file to find the last complete path and continues execution with the next one in sequence. Because of this restart capability, if for some reason, a case is being repeated using a previously used root file name, then the "MDS" file for the previous run must be deleted or moved to another directory before the new run is started. When all paths have been processed, the program calculates the field strength along each path using the parameters specified for the transmitting antenna and the receiver. These data are written to a file named with the extension "LWF" (for Long-Wave Fields).

If the propagation paths are set up automatically by user specification of an operating area, the program uses the data in the "LWF" file to generate a file named with the extension "GRD" (for Grid). The "GRD" file contains values of the signal strength and its standard deviation in a grid of latitude *versus* longitude that covers the user-specified operating area. At the same time, a corresponding grid file is written for the atmospheric noise. If the noise values are calculated for the NTIA

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model, then the file is named with the extension "NTI", if for the ITSN model, it is named with the extension "ITS", and if for the Long-Wave Noise Program, it is named with the extension "LNP". These noise models will be described in detail later in this document. Even though the noise files have extensions other than "GRD", they have the same format and use as the "GRD" files containing signal strength data. These "GRD" files may now be used in GRDPLOT to obtain geographical displays of the signal levels, noise levels, signal-to-noise levels, or, together with "GRD" files for other transmitters, signal-to-jammer levels. The operating-area grids are set up to give the finest resolution permitted within the dimensions of the program. In LWPC–2.0, the grid has 145 points in longitude and 73 points in latitude. The program forces the spacing in the longitude and latitude to be a multiple of 2 ½°, which is also the minimum spacing allowed. The program also ensures that the grids align along 5° boundaries.

CONTROL STRINGS

The input and execution of this program are directed by the use of control strings, summarized in table 2. The use of control strings is illustrated by the sample cases. Each of the possible control strings and their associated data are described below. Lines in the input file with a blank in column 1 are treated as comments. This feature allows for convenient switching on and off of various program options and enables annotation of the input files.

Table 2. Basic control strings for LWPM.

```
        A blank in column 1 is for comments
FILE-MDS        DIRECTORY-LOCATION-OF-MDS-DATA-FILES
FILE-LWF        DIRECTORY-LOCATION-OF-LWF-DATA-FILES
FILE-GRD        DIRECTORY-LOCATION-OF-GRD-DATA-FILES
FILE-PRF        DIRECTORY-LOCATION-OF-PRF-DATA-FILES
FILE-NDX        DIRECTORY-LOCATION-OF-NDX-DATA-FILES
CASE-ID         CASE-IDENTIFICATION
TX-NTR          ROOT-FILE-NAME-FOR-TRANSMITTER-NUMBER-NTR
JX-NJR          ROOT-FILE-NAME-FOR-JAMMER-NUMBER-NJR
TX-DATA         TX-ID freq lat lon power inclination heading altitude
TX-DATA         TX-ID TX-SPECIFICATION-FILE
JX-DATA         JX-ID freq lat lon power inclination heading altitude
JX-DATA         JX-ID JX-SPECIFICATION-FILE
OP-AREA         AREA-ID op-lat1 op-lon1 op-lat2 op-lon2
OP-AREA         AREA-ID OP-AREA-SPECIFICATION-FILE
BEARINGS        bearing-1 bearing-2 ...
+BEARINGS       bearing-n bearing-m ...
RECEIVERS       rx-lat-1 rx-lon-1 rx-lat-2 rx-lon-2 ...
+RECEIVERS      rx-lat-n rx-lon-n rx-lat-m rx-lon-m ...
RANGE-MAX       range-max-of-paths-defined-with-BEARINGS-and-RECEIVERS
IONOSPHERE      LWPM DAY
IONOSPHERE      LWPM NIGHT
IONOSPHERE      LWPM MONTH/day/year hour:minute
IONOSPHERE      HOMOGENEOUS EXPONENTIAL beta hprime
IONOSPHERE      HOMOGENEOUS TABLE PROFILE-NAME
IONOSPHERE      CHI EXPONENTIAL PROFILE-NAME
IONOSPHERE      CHI TABLE PROFILE-NAME
IONOSPHERE      RANGE EXPONENTIAL PROFILE-NAME
IONOSPHERE      RANGE TABLE PROFILE-NAME
IONOSPHERE      GRID TABLE PROFILE-NAME
A-NOISE         NOISE-MODEL-NAME MONTH/day/year hour:minute band-width
RX-DATA         VERTICAL    altitude
RX-DATA         HORIZONTAL altitude
LWF-VS-DIST     lwf-dist-max lwf-dist-inc
MC-OPTIONS      MC-STEP mc-test wf-iterate
PRINT-SWG       print-swg
PRINT-MDS       print-mds
PRINT-MC        print-mc
PRINT-LWF       print-lwf
PRINT-WF        print-wf
GCPATH
LWFLDS
OPA-GRID
PRESEG
START
QUIT
```

FILE SPECIFICATION

FILE-MDS sets the directory path for the mode parameter data files. If not specified, the program uses the directory in which it is being run.

FILE-LWF sets the directory path for the files containing signal strength and phase *versus* distance (also called mode sums). If not specified, the program uses the directory in which it is being run.

FILE-GRD sets the directory path for the coverage grid data files. If not specified, the program uses the directory in which it is being run.

FILE-PRF sets the directory path for the profile specification files. If not specified, the program uses the directory in which it is being run.

FILE-NDX sets the directory path for the profile specification index files. If not specified, the program uses the directory in which it is being run.

TX-NTR and **JX-NJR** are used to define the root file name for the output files. The root file name is a character string with no embedded blanks. The **NTR** and **NJR** are optional numbers designating the corresponding transmitter and jammer number, respectively. The content and usage of these files are indicated by the extension appended to the root file name. For example, if *ROOT-FILE-NAME* is *Cutler*, then the program will generate files named "Cutler.MDS" and "Cutler.LWF".

COVERAGE SPECIFICATION

CASE-ID allows the user to introduce an arbitrary string of up to 80 characters into the data files. The programs that do graphical displays place this string in their output. Its purpose is to supplement the often purely numerical parameters that are also displayed.

TX-DATA and **JX-DATA** are used to specify the parameters of transmitters. The first parameter in the data string must always be the transmitter or jammer identifier, *TX-ID* or *JX-ID*, respectively. This identification can be up to 20 characters. The other parameters of the transmitter are its frequency in kHz, latitude in degrees north, longitude in degrees west, radiated power in kW, inclination in degrees from the vertical, geographical heading in degrees east of north, and altitude in km of the short dipole antenna. The initial value of all these parameters is zero, except for power, which has the initial value 1. The sign convention is that latitude south and longitudes east are negative. A vertical antenna is defined by an inclination of zero. There are two methods for defining these transmitter parameters. In the first method, the parameters are simply encoded in the data string. In the second, the parameters are read from a file named "XMTR.LIS". This file must be located in the directory containing the LWPC data files. This directory will be described later. The transmitter or jammer identification encoded in the control string is used to select the correct parameters from the file by matching the user-specified transmitter identification with one of those found in the file. If the transmitter parameters are encoded in the data string and they match those of a record in the transmitter list, then the user-specified transmitter identification string is changed to the one found in the file. If the parameters encoded in the data string are unique, then they are automatically added to the file. This frees the user from having to remember and repeat the parameters of the transmitters and enforces a consistent naming convention among multiple users of the program.

Figure 7 illustrates a transmitter specification file. Each record in the file must contain the identification, frequency, location, power, antenna orientation, and antenna altitude. The last record must

Tx-id	freq	lat	lon	pwr	incl	headng	alt	note
OMEGA-A	10.2	66.42	-13.137	10	0	0	0	Norway
OMEGA-B	10.2	10.702	61.639	10	0	0	0	Trinidad
OMEGA-C	10.2	21.405	157.831	10	0	0	0	Haiku
OMEGA-D	10.2	46.366	98.336	10	0	0	0	La Moure
OMEGA-E	10.2	-20.974	-55.29	10	0	0	0	La Reunion
OMEGA-F	10.2	-43.053	65.191	10	0	0	0	Argentina
OMEGA-G	10.2	-38.481	-146.935	10	0	0	0	Australia
OMEGA-H	10.2	34.615	-129.453	10	0	0	0	Japan
GBR	16.0	52.37	1.187	60	0	0	0	Rugby
NDT	17.4	34.967	-137.017	40	0	0	0	Yosami
Anthorn	19.0	54.915	3.273	1	0	0	0	Anthorn
NSS	21.4	39.0	76.5	250	0	0	0	Annapolis
NWC	22.3	-21.8	-114.15	1000	0	0	0	H.E.Holt
NPM	23.4	21.417	158.15	630	0	0	0	Lualualei
NAA	24.0	44.633	67.283	1000	0	0	0	Cutler
NLK	24.8	48.2	21.917	130	0	0	0	Jim Creek
end								

Figure 7. Sample transmitter specification file.

contain the string *END* as shown in the figure. The first record may be an optional header that contains no numerical data. This works because the program does not attempt to decode the data string until it finds a match between the user-specified *TX-ID* and an entry in the data file. The identification string supplied in the data string and the identification strings in the specification file are converted to uppercase characters before they are compared with each other. Thus, *Anthorn* is treated the same as *ANTHORN*. Blanks or commas separate the parameters in both the data string and the records of the specification file. The order of the values is important but not the format of the input (as long as it is compatible with the type of the variable). Thus, the careful alignment of columns shown in the figure is not necessary. Since the program does not process values beyond the antenna altitude, additional information may be included in the records following the antenna altitude, as illustrated.

OP-AREA is used to define a set of paths that span an operating area. These paths will be used to produce coverage maps. The control string defines the boundaries of the operating area. In a manner similar to that used for **TX-DATA** and **JX-DATA,** these boundaries can be specified in one of two ways. The first parameter in the data string must always be the area identification, *AREA-ID,* containing up to 20 characters. This identification may be followed by the latitude and the longitude of the lower left-hand corner and the upper right-hand corner of the area in order of its southern latitude, western longitude, northern latitude, and eastern longitude. Alternatively, if just the area identification is specified, the boundaries of the operating area are to be found in a file named "AREA.LIS" located in the directory that contains the LWPC data files. If *AREA-ID* is followed by a single parameter or string, then that parameter or string is assumed to be the name of an alternate file containing area specification data. In either of these latter two cases, the *AREA-ID* is used to select the parameters of the op area from the file.

Figure 8 illustrates an operating-area specification file. The file may begin with a header to identify the parameters to follow in a manner similar to that used in the transmitter specification file. The last record must contain the termination string *END.* As with the transmitter specification, the area identification is always converted to uppercase before testing for a match between that specified by

the user and that found in the file. If the operating-area parameters are encoded in the control string and they match those of a record in the LWPC data file named "AREA.LIS", then the user-specified area identification string is changed to the one found in the list. If the parameters encoded in the data string are unique, then they are automatically added to the file. This frees the user from having to remember and repeat the parameters of operating areas in the files.

```
area-id          lat1        lon1        lat2        lon2
Atlantic          10         100          75         -40
Pacific            5        -120          70         100
Arctic            40         -80          90         -80
Polar             40         -80          90         -80
world            -90         180          90         180
test               5        -170          30         150
end
```

Figure 8. Sample operating-area file.

When the **OP-AREA** control string is used, the bearing angles of the paths are selected automatically. In the first pass, a coarse selection is made at 15° intervals. A second pass adds paths at a bearing-angle resolution of 3°, chosen to ensure that significant low-conductivity areas that might be encountered by the paths are included. Furthermore, the lengths of the paths are truncated to conform to the dimensions of the operating area. In other words, each path is only as long as it needs to be to cover the operating area. This option is used to create a "GRD" file. The name of this file will be formed by concatenating the root file name defined by **TX-NTR** or **JX-NJR** and *AREA-ID*. For example, if *ROOT-FILE-NAME* is *Cutler* and *AREA-ID* is *Atlantic*, then the program will generate a grid file named "CutlerAtlantic.GRD".

BEARINGS, RECEIVERS, and **RANGE-MAX** provide an alternative method for specifying paths. The data provided by the control strings **BEARINGS** and **RECEIVERS** define the direction of the paths. The control string **RANGE-MAX** provides a single value used to define the length of all paths specified with these options. The initial value of *range_max* is 20,000 km. The control string **BEARINGS** is followed by a list of geographical bearing angles measured in degrees east of north. In the event that all bearing angles are not specified in one control string, additional values of bearings may be supplied by using the control string **+BEARINGS.** The maximum number of bearing angles that may be defined using one **BEARINGS,** together with additional **+BEARINGS,** is 120. Similarly, **RECEIVERS** is used to set up paths using a set of geographical positions. In this case, the data string is a list of pairs of coordinates in order of latitude and longitude. Additional pairs of coordinates may be supplied by using the control string **+RECEIVERS.** Only pairs of coordinates are allowed so that use of **+RECEIVERS** requires that the first value in the data string be latitude. The maximum number of receivers is 60. If the paths are defined by using **RECEIVERS,** then an extra value of signal strength is computed by the LWPM at the distance defined by the receiver coordinates. This extra value is found at the end of print outs of the "LWF" files (to be discussed later).

A-NOISE is used to specify the parameters of the atmospheric noise to be computed over the operating-area grid. This calculation is performed only when using **OP-AREA** to set up the paths. The first parameter in the data string is the name of one of the noise models currently available. *ITSN* names the ITS noise model of Zacharisen and Jones (1970), *NTIA* names the noise model of Spaulding and Washburn (1985), and *LNP* names the noise model of Warber and Shearer (1994). The data files for the *ITSN* and *NTIA* models are calculated by the program. A separate program, which is not

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part of the LWPC, must provide the data files for the *LNP* model. The date and time for which the noise is to be computed are specified by the date and time encoded in the data string. A string of the form *MONTH/day/year* specifies the date where *MONTH* is the name of the month. A string of the form *hour:minute* specifies the time. The last parameter in the data string is the *bandwidth* in Hz for the noise computation. The initial value of the noise model is *NTIA* and of the *bandwidth* is 1000 Hz. The initial value of the day, year, and time is zero. There is no initial value for the month.

PRESEG is used to provide user-specified path segmentation data overriding the LWPM's automatic segmentation. This control string is followed by a series of records that list distances from the transmitter and associated path parameters. The path parameters are distance in km, geomagnetic azimuth in degrees east of north, geomagnetic dip in degrees from the horizontal, strength of the geomagnetic field in Webers/m^2, ground conductivity index, ground conductivity in Seimens, ratio of the dielectric constant of the ground to that of free space, ionospheric profile index, the slope of an exponential ionosphere (β) in km^{-1}, and its reference height (h') in km. The first record must be for zero distance. The records are read by using a list-directed format in which each one must contain either a value or a placeholder for missing parameters (indicated by consecutive commas). The distance from the transmitter must be given, but the remaining parameters are optional. If a placeholder is used for any of the geomagnetic parameters, then the LWPM calculates the relevant value. The user may elect to use the LWPM's ground-conductivity values by setting the ground-conductivity index instead of directly setting the conductivity and the ratio of the dielectric constant relative to free space of the ground. Table 3 shows the ground-conductivity indices for the ground conductivity used in the LWPM. Thus, the user may vary the actual ground-conductivity parameters or override the built-in map by controlling the ordering of the default values. If placeholders fill all of the fields for the ground conductivity, the LWPM will provide values by using the default model. Similarly, the user may use the profile index either to override the order of the built-in ionospheric parameters or to specify arbitrary values. Consistent with table 1, the values in table 4 show the ranges of the solar zenith angle, the associated ionospheric profile parameters used in the LWPM, and their associated profile indices. Alternatively, the profile indices may refer to a set of user-specified ionospheric profiles. This feature is described in detail in the section on ionospheric specification. Figure 9 shows a simple example of user-specified segmentation of a path.

Table 3. Default ground-conductivity indices for the LWPM.

Index	σ	$\varepsilon/\varepsilon_0$
1	1×10^{-5}	5
2	3×10^{-5}	5
3	1×10^{-4}	10
4	3×10^{-4}	10
5	1×10^{-3}	15
6	3×10^{-3}	15
7	1×10^{-2}	15
8	3×10^{-2}	15
9	1×10^{-1}	15
10	4	81

Table 4. Default ionospheric-profile indices for the LWPM.

Index	Solar Zenith Angle (χ) (deg)					β (km^{-1})	h' (km)
1	−180.0	<	χ	<	−99.0	0.30	87.0
2	−99.0	<	χ	<	−97.2	0.30	84.8
3	−97.2	<	χ	<	−95.4	0.30	82.7
4	−95.4	<	χ	<	−93.6	0.30	80.5
5	−93.6	<	χ	<	−91.8	0.30	78.3
6	−91.8	<	χ	<	−90.0	0.30	76.2
7	−90.0	<	χ	<	90.0	0.30	74.0
8	90.0	<	χ	<	91.8	0.30	76.2
9	91.8	<	χ	<	93.6	0.30	78.3
10	93.6	<	χ	<	95.4	0.30	80.5
11	95.4	<	χ	<	97.2	0.30	82.7
12	97.2	<	χ	<	99.0	0.30	84.8
13	99.0	<	χ	<	180.0	0.30	87.0

```
tx                              dec00
ionosphere   lwpm Dec/15/1996 00
preseg
        0,,,,  5,,,12,,,
     1340,,,,10,,,13,,,
     4020,,,,  6,,,13,,,
     4920,,,,  6,,,  9,,,
     5200,,,,  6,,,  8,,,
     6000,,,,  6,,,  7,,,
    40000
    start
```

Figure 9. Sample of user-specified path segmentation.

START indicates that all user-specified input is complete and that execution is to begin. This control string is required to obtain any output from the program.

QUIT terminates the current run.

IONOSPHERIC SPECIFICATION

IONOSPHERE is used to specify the diurnal condition over all the propagation paths of a specific run. The first parameter in the data string defines the ionospheric model. Five models are recognized: *LWPM, HOMOGENEOUS, CHI, RANGE,* and *GRID*. The first of these models is the default for the LWPM program. This model is described elsewhere in this document. The *HOMOGENE-OUS, CHI, RANGE,* and *GRID* models allow the user to override the default model. The *HOMOGENEOUS* model is used to specify a uniform ionosphere over all propagation paths. The *RANGE* model is used to examine a single propagation path. In this model, the user specifies a range-dependent ionospheric variation. The *GRID* model is intended for problems in which the ionosphere varies over a user-specified geographic grid. The *CHI* model allows the user to specify profiles that depend on the solar zenith angle, basically overriding the default model.

If *LWPM* is specified, substrings specifying the diurnal condition to be applied follow. If the substring is *DAY,* then the diurnal condition over the whole path is daylight. If the substring is *NIGHT,* then the diurnal condition over the whole path is night. The definition of the nighttime ionosphere includes the lower effective height of the ionosphere at polar latitudes. Although physically unrealistic, these two conditions are useful for some kinds of analyses. Finally, a specific date and time may be specified by using two substrings. The date substring contains the name of the month, the day of the month, and the year in the form *MONTH/day/year.* The date substring is followed by the time substring, which contains the Universal time (UT) in the form *hour:minute.* The date and time are used to find the location of the day-night transition from which an appropriate variation of the parameters of the ionospheric profile is defined along the path. The date substring must contain at least the name of the month. To set just the month and day, */year* may be dropped. The calculations of the LWPC depend on the year only in so far as the position of the sun as seen on the earth shifts slightly from year to year. Similarly, just the month may be specified by dropping */day/year.* The time substring must contain at least the hour. To set just the hour, *:minute* may be deleted. The initial value for this string is *LWPM DAY.*

Two sets of substrings may follow the *HORIZONTAL* model name. The first set is indicated by *EXPONENTIAL,* which is followed by the numerical values of the slope and reference height of the profile: *beta* and *hprime.* The second substring is *TABLE.* This substring is followed by the root name of a file named *"PROFILE-NAME"* used to specify the names of files required for tabular input. A number of options are available for setting up tabular profiles. These options will be discussed below.

If the ionospheric model is *RANGE EXPONENTIAL,* the specification of the ionosphere along the path is done in a file with a name of the form *"PROFILE-NAME.NDX"*. This file contains a list of records, each containing the range and its associated slope and reference height (β, h'), with optional comments (records with a semicolon in column 1) as illustrated in figure 10.

```
;Date and time
;Apr/15 22:00
;Bearing angle at 24
;   rho        beta     hprime
         0     0.30     74.0
       420     0.30     74.0
      1020     0.30     74.0
      1140     0.30     74.0
      1340     0.30     74.0
      2400     0.30     74.0
      2520     0.30     74.0
      2760     0.30     74.0
      3000     0.30     74.0
      3720     0.30     74.0
      4640     0.30     76.2
      4740     0.30     76.2
      4880     0.30     78.3
      5120     0.30     80.5
```

Figure 10. Sample "*PROFILE-NAME.NDX*"
file for *RANGE EXPONENTIAL* option.

TABULAR PROFILES

Setting up tabular profiles is relatively straightforward although it can be somewhat tedious. Two basic files should be supplied. For range-dependent cases (to be discussed below) a third (index) file is needed to set the profile to be used at each distance. The first of these basic files must be named with the form "*PROFILE-NAME000.PRF*" where the "*000*" are all zeroes. This file is an initialization file that sets up the number of species of charged particles in the ionosphere (up to 3), the collision frequency, etc., as shown in table 5 and discussed below. If this file is not found, then default values are used. The second type of file, with a name of the form "*PROFILE-NAMEnnn.PRF*", specifies the charge densities as a function of height. The parameter "*nnn*" is the profile index that is defined by the user. If the ionospheric model is *HOMOGENEOUS TABLE*, then "*nnn*" is not required. Note that the extension in all cases is "PRF". The index file (if needed) must have a name of the form "*PROFILE-NAME.NDX*".

Table 5. Control strings for tabular profiles.

;comment			
SPECIES	*number-of-species*		
CHARGE	*charge-e*	*charge-i1*	*charge-i2*
MASS-RATIO	*ratio-e*	*ratio-i1*	*ratio-i2*
COEFF-NU	*nu0-e*	*nu0-i1*	*nu0-i2*
EXP-NU	*exp-e*	*exp-i1*	*exp-i2*
COLLISION-FREQUENCY-TABLE			
DENSITY-TABLE			
MODEL-PRF	*FORMATTED*		
MODEL-PRF	*UNFORMATTED*		
MODEL-PRF	*MODEL-NAME*		

The first record in the "PRF" files is identification. For example, a set of profiles created to simulate a specific environment might all have the same identification, such as "Ionospheric disturbance."

Subsequent records in the "PRF" files specify additional profile parameters. Specification of these other parameters in the profile files is handled with control strings in a manner similar to that used by the rest of the program, except that a semicolon in column 1 is used for comments instead of a blank. This departure from that used by the control strings is due to the frequent use of formatted columnar data in this form of input.

Table 5 summarizes the control string for the profile files. **SPECIES** specifies the number of species in the profile table. The maximum number of species is 3; the default value is 1. If the number of species is 3, then it is assumed that they are electrons, positive ions, and negative ions. **CHARGE** specifies the charge of each species; the default values are 1, –1, and 1. **MASS-RATIO** specifies the mass of each species relative to that of an electron; the default values are 1, 58000, and 58000. It is assumed that the first species is electrons so the first value of charge and mass ratio is always 1. The collision frequency may be specified in one of two ways. If an exponential collision frequency is to be used, then the control strings **COEFF-NU** and **EXP-NU** are used. **COEFF-NU** specifies the collision-frequency at the ground in collisions per second; the default values are 1.816×10^{11}, 4.54×10^9, and 4.54×10^9. **EXP-NU** specifies the slope of exponential decay of the collision-frequency in km^{-1}; the default values are all -0.15 km^{-1}. Alternatively, a tabular collision-frequency profile may be needed. In that case, the control string **COLLISION-FREQUENCY-TABLE** is used. This control string is followed by a table of collision frequencies as a function of height, in descending order of height. Each record in this table contains the height in km, the electron collision frequency, the first-ion collision frequency, and the second-ion collision frequency. If the second-ion collision frequency is not specified, then it is assumed to be the same as the first. The collision frequencies are specified as collisions per second. The list of collision frequencies is terminated by a dummy height of any negative value.

MODEL-PRF specifies the format of the charge density tables found in the files "*PROFILE-NAMEnnn.PRF*" described above. *FORMATTED* indicates the files are formatted in the same way as described for **COLLISION-FREQUENCY-TABLE**. *UNFORMATTED* indicates the files are unformatted with the data being stored as follows: *nrspecies*, *nrhts*, (*hten*(i), (*algen*(i,k), *k=1,nrspecies*), *i=1,nrhts*), where *nrspecies* is the number of species, *nrhts* is the number of heights, *hten* is a list of heights, and *algen* is a list of the natural logarithm of each of the charge densities. These variables are all 4 bytes long. It should be evident that such a binary file should be created using the same FORTRAN compiler and operating system used to build the LWPC. The lists are input in order of descending altitude. *MODEL-NAME* indicates the files are formatted according to a specific model that requires a corresponding input-processing routine supplied by the user. Figure 11 shows a sample initialization file. Defaults are used for everything but the collision frequency and the number of species.

```
SIMBAL
;The first line (above) is the profile identification string
Species 3
Collision-Frequency-Table
    100.00      5.75e+04  1.06e+04
     95.00      1.27e+05  2.06e+04
     90.00      2.91e+05  4.19e+04
     85.00      6.82e+05  8.58e+04
     80.00      1.58e+06  1.70e+05
     75.00      3.53e+06  3.21e+05
     70.00      7.52e+06  5.79e+05
     65.00      1.54e+07  1.01e+06
     60.00      3.05e+07  1.69e+06
     55.00      5.86e+07  2.77e+06
     50.00      1.10e+08  4.50e+06
     45.00      2.08e+08  8.60e+06
     40.00      4.05e+08  1.72e+07
     35.00      8.19e+08  3.57e+07
     30.00      1.73e+09  7.72e+07
     25.00      3.74e+09  1.69e+08
     -9.
```

Figure 11. Sample "*PROFILE-NAME000.PRF*" file.

The files named "*PROFILE-NAMEnnn.PRF*" are of the same form as the initialization file with the control string **DENSITY-TABLE** being used to specify the particle densities in place of the control string **COLLISION-FREQUENCY-TABLE**. This control string is followed by a table of charged-particle densities as a function of height. The values are input in order of descending height. Each record in this table contains the height in km, the electron density, and the ion density. The program computes the second-ion density to preserve charge neutrality. The charge densities are specified as particles per cubic centimeter. The list of densities is terminated by any height of negative value. Figure 12 shows a file containing a tabular profile.

```
PRFLSCN 1  INDEX 270
Density-Table
    100.00  3.62E+04  3.62E+04
     95.00  1.23E+04  1.23E+04
     90.00  6.75E+03  6.75E+03
     85.00  3.47E+03  3.47E+03
     80.00  1.21E+03  2.23E+03
     75.00  1.08E+03  1.64E+03
     70.00  1.87E+03  1.95E+03
     65.00  2.16E+03  2.61E+03
     60.00  1.83E+03  5.21E+03
     55.00  5.85E+02  1.73E+04
     50.00  6.09E+01  3.12E+04
     45.00  5.34E+00  3.61E+04
     40.00  1.51E+00  3.51E+04
     35.00  4.02E-02  3.75E+03
     30.00  1.19E-02  4.58E+03
     25.00  2.93E-03  5.04E+03
     -9.00
```

Figure 12. Sample *"PROFILE-NAMEnnn.PRF"* file.

If the ionospheric model is *HOMOGENEOUS*, then the foregoing descriptions are enough to set up the model. On the other hand, if the model is *RANGE TABLE*, then additional set up is required. In this case, there must be a set of profile files with names of the form *"PROFILE-NAMEnnn.PRF"*, where *nnn* is a profile index number. The indexing is completely up to the user, but the value encoded in the file name must always be 3 digits. Each of these files contains a tabular profile of the form shown in figure 12. Another file is required to specify the range at which each profile is used. This file must have a name of the form *"PROFILE-NAME.NDX"*. This file is simply a list of records, each containing the range and its associated profile index, with optional comments as illustrated in figure 13.

```
;prflscn 1, test run, rbear= 50.0
;range index
      0   447
   1580   348
   2080   270
```

Figure 13. Sample *"PROFILE-NAME.NDX"* file
for *RANGE TABLE* option.

The ionospheric model *GRID TABLE* provides a means for an elaborate geographical distribution of the ionosphere. The preparation of the necessary database is best accomplished with a standalone program. The basic features described above for range-dependent tabular profiles are applied in this case. However, the index file is much more complicated. The user is strongly advised to study the subroutine named PRFL_GTBL.FOR found in the distribution library named PRF before attempting to use this option.

OVERRIDING THE SOLAR ZENITH ANGLE DEPENDENCE

The remaining ionospheric models are *CHI EXPONENTIAL* and *CHI TABLE*. These models allow the user to override the solar zenith angle dependence used in the *LWPM* model. The setup of these models is similar to that in *RANGE EXPONENTIAL* and *RANGE TABLE* except that values of the solar zenith angle replace values of range in the index files. However, the user must always provide 7 sets of values to be consistent with the LWPM model. Figure 14 illustrates a sample index file for the *CHI EXPONENTIAL* model. In this example, the day-to-night transition is shortened from 9° to 3°. The variation of β and h' from day to night is controlled by the user. In this case, a simple linear variation was chosen. If the tabular form of this model is used, then the pair of columns for β and h' is replaced by a single one specifying user-defined profile indices.

```
;Change length of terminator from 90-99 to 96-99
;Set beta & hprime for 30 kHz
;chi    beta   hprime
    0   0.30   74.0
   96   0.33   76.2
 96.6   0.37   78.3
 97.2   0.40   80.5
 97.8   0.43   82.7
 98.4   0.47   84.8
   99   0.50   87.0
```

Figure 14. Sample "*PROFILE-NAME.NDX*" for *CHI EXPONENTIAL* model.

OPTIONAL OUTPUTS

GCPATH indicates that geophysical parameters along the propagation paths are to be computed and printed. The control string **START** must follow it. This option does not result in the calculation of mode parameters along the paths. The geophysical parameters printed are the orientation of the path with respect to the direction of propagation, the ground conductivity, dielectric constant, and the ionospheric parameters, β and h'. This is a handy way for the user to get values for setting up some of the more elaborate ionospheric models described above.

RX-DATA is used to define parameters for the received fields. The first parameter is a character string indicating the orientation of the fields, and the second parameter is the altitude at which the fields are computed. The vertical electric field, TM or E_z, is obtained with the string *VERTICAL*. Both the vertical and horizontal fields, TM and TE or E_z and E_y, are calculated if the string is *HORIZONTAL*. Both of the strings may be shortened to the first character. The initial value of the component is *VERTICAL*, and the altitude at which the field is computed is zero.

LWF-VS-DISTANCE defines the ending distance and the distance increment in km over which the field strength is to be computed. The initial value of the ending distance is 20,000 km. The initial value of the distance increment is 20 km. Although mode parameters are computed over varying lengths of paths, the fields are computed to the same range from the transmitter for all paths. The distance increment must be such that *lwf-dist-max* divided by *lwf-dist-inc* is less than 1001.

LWFLDS is used to obtain additional signal-strength calculations. The most time-consuming process in the LWPC is the generation of the mode parameters along the propagation paths. The

calculation of the signal strength along the paths is relatively quick, so a separate mode-summing procedure is available. In the event that the user wants to calculate mode sums for different values of the transmitter antenna (*inclination, heading,* and *talt*) or receiver parameters (*VERTICAL* or *HORIZONTAL* or *ralt*), the parameters are changed by using the corresponding control strings. The control string **LWFLDS** followed by **START** does new signal-strength calculations and overwrites the existing "LWF" file. In the event that review of the graphs of signal strength *versus* distance reveals unusual patterns, the user may choose to recalculate the signal-strength data by using the full-wave mode-conversion model described below. This would be accomplished by using the appropriate control strings for the full-wave model (see **MC-OPTIONS**) followed by **LWFLDS** and **START**.

OPA-GRID is used to obtain additional operating-area grid files. An important use of the LWPC is the generation of coverage displays. This is the reason that the specification of propagation paths over operating areas is automated. If a mode sum is redone (see **LWFLDS**) or the boundaries of the operating area are changed, then a new file of grid data must be generated by using the control string **OPA-GRID** followed by **START.** This procedure can be used to enlarge the geographical area enclosed by the grid file. However, enlarging the boundaries of the operating area must be done with caution. The extent of each propagation path is selected to reach just beyond the boundary of the originally specified operating area and may not be valid for a much larger area.

MC-OPTIONS controls the mode-conversion calculation. The LWPC uses a mode-conversion model (Ferguson and Snyder, 1980) to connect the series of horizontally homogenous segments along every propagation path. The most accurate implementation of the mode-conversion model integrates the radio fields vertically over the boundary between segments. This integration can be quite time consuming. A reasonably accurate and faster running implementation replaces the full-wave integration with an approximation based on the notion that most of the interaction of the radio wave takes place within the reflection height of the ionosphere. The default implementation of the mode-conversion model is the approximate one. In rare cases, the full-wave model must be employed to ensure accuracy. The control string **MC-OPTIONS** in table 2 is used to control the mode-conversion model used by the program. The parameter named *MC-STEP* may have one of three values. *FULL-WAVE* calls for the full-wave calculations to be performed. *APPROXIMATE* indicates that only the approximate form of the calculations is to be used. *MIXED* indicates that a mix of full-wave and approximate calculations is to be performed. The *MIXED* implementation uses the approximate model except when the reference height of the ionosphere, h', is greater than a user-specified value, set by *mc-test.* In some instances, this mix of full-wave and approximate models can give results almost as good as the full-wave model but in much less computer time. Unfortunately, one often has to run the full-wave model in order to verify the mixed results. If the full-wave model is to be employed, the user may choose to have the mode-conversion algorithm use the mode parameters as calculated by the LWPM or to have it iteratively refine them to ensure the accuracy of the results. It is recommended that the iteration be used since the user is already accepting a large penalty in time for employing this model. Setting *wf-iterate* to TRUE turns on the iteration.

The control strings that begin **PRINT-** are used to obtain additional output during the processing along each propagation path. These outputs can be quite voluminous. The initial value of each of these parameters is zero, minimizing the output. **PRINT-SWG** is used to obtain additional output from the LWPM during generation of the mode parameters along the propagation path. **PRINT-SWG** can have 4 values: 0 turns off the extra printout, 1 prints path parameters and a list of the mode solutions, 2 adds a listing of the mode parameters, and 3 adds a printout of extrapolation results. These parameters are written to the log file as they are computed along the paths. This output can be confusing because the program does not always process the segments of the paths in sequential order

starting at the transmitter. **PRINT-MDS** controls output while the program reads and writes the "MDS" file during the calculation of the signal strength along the path. It can have 2 values: 0 gives very terse summary output, and 1 adds a printout of the modes' attenuation rate, etc. This output is in order of increasing distance from the transmitter. **PRINT-MC** provides additional output during the calculation of the mode sum. It can have 3 values: 0 produces a summary of the calculations, 1 adds output of the mode-conversion coefficients, and 3 adds a printout of the integrals over the slab boundary. **PRINT-LWF** prints a summary of the signal-strength calculation as it is written to an "LWF" file. It can have 2 values: 0 gives a very terse summary, and 1 prints out the signal strength as a function of distance from the transmitter along the path. **PRINT-WF** provides output only when the full mode-conversion model is being used. It can also have 3 values: 0 turns off the printout, 1 prints the results of the iterations on the mode solutions, and 2 adds a printout of the results of the integration of the fields *versus* height.

PLOTTING THE RESULTS

The program LWPM does not directly provide for the graphical display of its output. Instead, separate programs, to be described in this section, generate graphical displays. The names of the programs are based on the type of file they process or the quantity to be displayed: LWFPLOT plots signal strength and phase *versus* distance, and GRDPLOT plots maps of contours of constant signal strength, atmospheric noise level, signal-to-noise ratio, and signal-to-jammer ratio in geographical displays. These programs use many of the same control strings already described for use by LWPM, in addition to several others that will be described below. In some instances, there are fewer parameters in the data strings than used by the LWPM.

PREVIEW PLOTS

The program PRVWPLOT provides a graphical display of the propagation paths and their segmentation as determined by the LWPM. This allows the user to get some idea of the magnitude of the case to be run before starting it and provides a useful display for presentations and review. This program accepts all the control strings used in the LWPM to eliminate the possibility of errors in setting up the two different runs. Table 6 shows additional control strings unique to PRVWPLOT (and also GRDPLOT). One of the sample cases provided with the software distribution is for this program, and a sample graph is shown later on in figure 23.

Table 6. Controls strings used by PRVWPLOT.

PLOTTER	*PLT–DEVICE*						
MAP–AREA	*MAP–ID RECTANGULAR*	*lat1*	*lon1*	*lat2*	*lon2*	*size–x*	*size–y*
MAP–AREA	*MAP–ID MERCATOR*	*lat1*	*lon1*	*lat2*	*lon2*	*size–x*	*size–y*
MAP–AREA	*MAP–ID GNOMONIC*	*lat0*	*lon0*	*RANGE*		*size–x*	*size–y*
MAP–AREA	*MAP–ID AZIMUTHAL*	*lat0*	*lon0*	*RANGE*		*size–x*	*size–y*
MAP–AREA	*MAP–ID ORTHOGRAPHIC*	*lat0*	*lon0*	*RANGE*		*size–x*	*size–y*
MAP–AREA	*MAP–ID STEREOGRAPHIC*	*lat0*	*lon0*	*RANGE*		*size–x*	*size–y*
MAP–AREA	*MAP–ID MAP–AREA–SPECIFICATION–FILE–NAME*						
MAP–TYPE	*LAND*						
MAP–TYPE	*COAST*						
MAP–TYPE	*CONDUCTIVITY*						
MAP–TYPE	*COAST LAND*						
MAP–TYPE	*COAST CONDUCTIVITY*						

PLOTTER defines the plotting display device: *PLT-DEVICE*. This parameter may specify one of two operating-system devices. One device is the screen, identified as *SYS-SCN,* and the other is the local default printer, identified as *SYS-PRN*. Each of these strings may be shortened to the first five characters. If *PLT-DEVICE* is just *SYS*, then *SYS-SCN* is implied. The graphical output may be directed to any printer installed on the system provided it is the current default printer. Thus, if more than one printer is available, the user must manually set the desired one as the system's default printer. If *PLT-DEVICE* is neither of the values specified above, the graphical output is written to a file named by the string found in *PLT-DEVICE*. This file may be imported as an HGL formatted file into PowerPoint. This is especially easy if the named file has the extension "HGL".

MAP-AREA defines the projection, boundaries, and dimensions of the geographical area upon which the operating area and the propagation paths are to be plotted. The map parameters are defined in a manner similar to that used to define the boundaries of the operating area. The first parameter in the data string must be the map identification, *MAP-ID,* having up to 20 characters. If the *MAP-ID* is not followed by any other information, then it is assumed that the parameters of the map are to be found in the map specification file named "MAP.LIS", found in the directory containing the LWPC data files. This file will be searched for a record containing a match to the specified *MAP-ID*. If the *MAP-ID* is followed by a single parameter, that parameter is assumed to be the name of an alternate map area specification file, which will be searched for a record containing a match to the specified *MAP-ID*. Otherwise, the program expects to find the name of the projection and the map parameters, which depend on the projection.

The following projections are available: rectangular, Mercator, gnomonic, azimuthal equidistant, orthographic, and stereographic. Examples of all the projections except the Mercator projection are shown below for a common scenario. The rectangular projection is a cylindrical map projection that is linear in both latitude and longitude. Thus, this projection distorts the high latitudes. Figure 1 shows an example of this projection. The Mercator projection is the projection used in the traditional wall map. It shows severe distortion for latitudes above approximately 50°N. The azimuthal equidistant projection maps all of the points at the same distance from the center of the projection onto a circle. The points are placed along radials corresponding to the geographic bearing angle as measured at the center point. Figure 15 is an example of an azimuthal equidistant projection. The gnomonic projection is used in sailing charts because this projection maps great circles as straight lines. This characteristic is clearly seen in figure 16. However, the gnomonic projection severely distorts areas far from the center of the map. The orthographic projection (figure 17) shows the earth as seen from far out in space. There is very little distortion in this map since it is similar to viewing a globe. The stereographic projection (figure 18) is similar to the gnomonic except that the areas near the center of the map are shown with very little distortion.
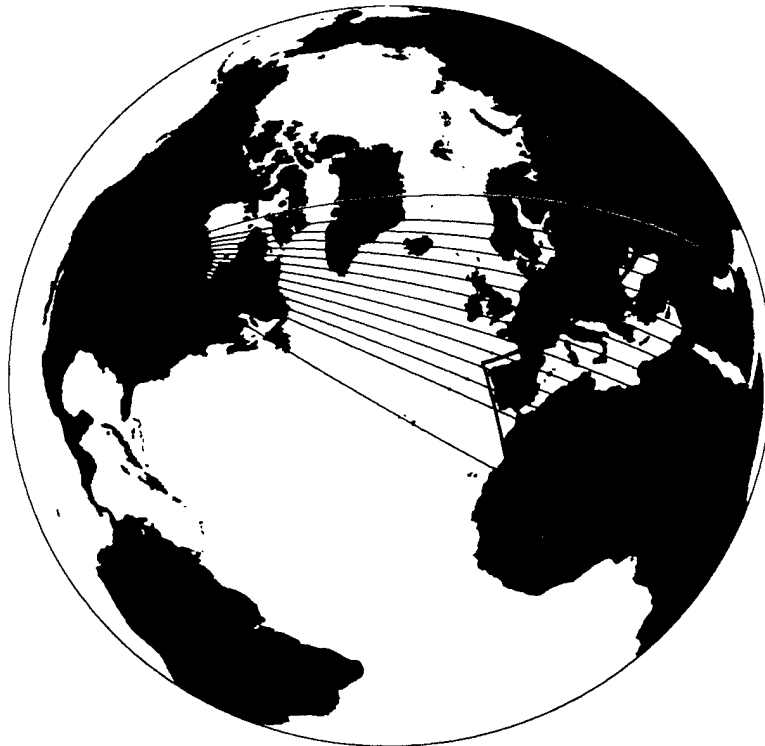
Azimuthal equidistant centered at (45N 30W)

Figure 15. Azimuthal equidistant projection.
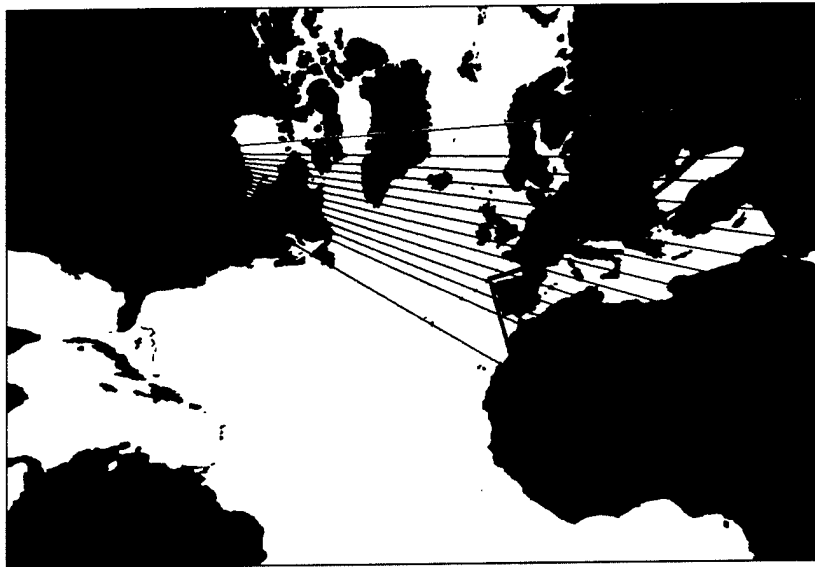
Gnomonic centered at (45N 30W)

Figure 16. Gnomonic projection.

Orthographic centered at (45N 30W)

Figure 17. Orthographic projection.

Stereographic centered at (45N 30W)

Figure 18. Stereographic projection.

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The rectangular and Mercator projections specify the boundaries of the map in order of its southern latitude, western longitude, northern latitude, and eastern longitude and the dimensions of the map. Following the conventions of the LWPC, latitudes are given in degrees North, and longitudes are given in degrees West. The dimensions of the map are in inches. A center point, given in order of the center latitude and longitude, and the maximum range to be displayed in km define all the gnomonic, azimuthal equidistant, orthographic, and stereographic projections. The names of the projection may be shortened to the first four characters. The parameters associated with each projection are shown in the header records of the sample map specification file shown below.

If the map parameters are to be found in a file, then the records of that file must contain the map identification, the name of the projection, the boundaries of the map, and the dimensions of the map. Figure 19 illustrates a map-area specification file. The file may begin with a header similar to that used in the operating-area specification file. In this sample, there are several headers, one for each projection. The last record contains the termination string *END*. The *MAP-ID* is used to select the parameters of the map from the file. As with the op-area specification, the map identification is always converted to uppercase before testing for a match between the user's specification and that found in the file. Furthermore, the name of the projection supplied by the user or by the file is converted to lowercase before testing for the projection to be used.

map-id	rect	lat1	lon1	lat2	lon2	size-x	size-y
map-id	merc	lat1	lon1	lat2	lon2	size-x	size-y
map-id	gnom	lat0	lon0	range		size-x	size-y
map-id	azim	lat0	lon0	range		size-x	size-y
map-id	orth	lat0	lon0	range		size-x	size-y
map-id	ster	lat0	lon0	range		size-x	size-y
north000	rect	0	0	90	0	7	4
north180	rect	0	180	90	180	7	4
N-Atlant	rect	0	100	90	-40	7	4
N-Pac	rect	-20	-120	70	100	7	5
Polar	gnom	90	100	6000		7	5
world	rect	-90	180	90	180	7.5	6
globe	orth	40	70	10000		7.5	6
end							

Figure 19. Sample map-area file.

If the user specifies the map parameters, then the default map specification file, "MAP.LIS", is updated by using the new values. If the specification file already contains an entry with the same identification as the user's, then the parameters in the file are compared with the values supplied by the user. Except for the dimensions of the map, if every value specified by the user does not match those found in the specification file, then the run is aborted. This is done to require a consistent naming convention for the map areas.

If the control string **OP-AREA** is used to define the coverage area, then PRVWPLOT shows the boundaries of the specified operating area. So, the best display is obtained by making the map area large enough to show the whole operating area.

MAP-TYPE is used to define the way the landmasses are to be delineated. The data string may have one or two values. The basic map types are landmasses, ground conductivity, and coastal outline. If the landmass or ground-conductivity maps are used, a second map type (usually the coastal outline) may also be used for emphasis. Table 6 shows the various combinations. If this control string is omitted, then the boundaries of the operating area and the propagation paths are plotted without delineating the landmasses.

FIELD STRENGTH PLOTS

The LWFPLOT routine plots signal strength as a function of distance from the transmitter in dB above $1\mu V/m$. Data for each path are plotted in separate graphs. If more than one field component is in the file, the program plots each component with different line styles and colors on the same graph. The program also plots two additional lines at the bottom of each graph. One of these lines represents the height of the ionosphere and the other the ground conductivity. The plot representing the ground conductivity also contains a symbol indicating the beginning of each segment along the propagation path. These data are taken from the path segmentation data, which are part of the file. As a reminder, a legend for these quantities appears at the lower right edge of each graph. The label below each graph includes the name of the program that generated the file, and the date the file was generated. The latter helps keep track of which version of the program was used. Table 7 is a summary of the control strings used by this program. Those that are unique to the LWFPLOT are described below. One of the sample cases provided with the software distribution is for this program, and a sample graph is shown later on in figure 28.

TX-NTR and **JX-NJR** are used to name the files that contain the signal strength *versus* distance data. Although not encoded in this data string, there must exist corresponding files with the extension "LWF". The substrings *NTR* and *NJR* carry over from the LWPM to help the user keep things organized but only one transmitter may be plotted at a time (the last one in the input file before the **START** control string).

Table 7. Controls strings used by LWFPLOT.

PLOTTER	*PLT-DEVICE*
FILE-LWF	*DIRECTORY-LOCATION-OF-LWF-DATA-FILES*
TX-NTR	*TX-FILE-NAME*
JX-NJR	*JX-FILE-NAME*
BEARINGS	*list-of-path-bearing-angles-to-graph*
MODIFY-PWR	*power*
DIST-AXIS	*scale-x size-x dstmax dsttic*
AMPL-AXIS	*scale-a size-a ampmin ampmax amptic*
PHAS-AXIS	*scale-p size-p phsmin phsmax phstic UNITS*
PHAS-PLOT	*OPTION*
PRINT-LWF	*print-lwf*
RUNNING-AVG	*nravg*
START	
QUIT	

FILE-LWF sets the directory path for the mode sum files. If not specified, the program uses the directory in which it is being run.

BEARINGS is used to select specific paths from the input file. If the data string is not blank, then the input file is searched for the designated bearing angles. If a designated bearing angle is found in

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the file, then signal strength *versus* distance is plotted. If this control string is not used, then all paths in the file are plotted.

MODIF-PWR is used to change the transmitter or jammer power to the specified value in kW, before plotting the curves of signal strength *versus* distance.

DIST-AXIS contains parameters used to scale the horizontal axis of the graphs. If the parameter *scale-x* is zero, then the next three parameters are used. If *scale-x* is not zero, then the vertical size of the graph is determined from *dstmax, dstmin,* and *scalex.* If *dstmax* is −99 (default), then the maximum value is determined from the input array of distances. All the distance values are in km. The scale is kilometers per inch.

AMPL-AXIS contains parameters used to scale the vertical axis of the amplitude graphs. If the parameter *scale-a* is zero, then the next three parameters are used. If *scale-a* is not zero, then the horizontal size of the graph is determined from *ampmax, ampmin,* and *scale-a.* If *ampmax* is −99 (default), then the maximum value is determined from the input array of signal strengths. All the amplitude values are in dB above 1 μV/m. The scale is dB per inch.

PHAS-AXIS contains parameters used to scale the vertical axis of the phase graphs. If the parameter *scale-p* is zero, then the next three parameters are used. If *scale-p* is not zero, then the horizontal size of the graph is determined from *phsmax, phsmin,* and *scale-p.* If either *phsmax* or *phsmin* is −99 (default), then the corresponding value is determined from the input data. The units of the phase axis are set by *UNITS*, which may be *DEGREES* or *MICROSEC*.

PHAS-PLOT turns plots of the phase on and off by setting *OPTION* to *YES* or *NO*.

RUNNING-AVG is used to control averaging of the input data before it is graphed. The value of *nravg* specifies how many points are averaged. This is a running average so that a value output at a specific range is the average of the input value at the range and *(nravg-1)/2* values before and after the range. Thus, it is common to use odd numbers for *nravg*.

COVERAGE PLOTS

The most commonly used graphical output program in the LWPC is GRDPLOT. This program plots contours of constant signal, signal-to-noise ratio, and signal-to-jam ratio in a geographical display. The geographical areas are defined the same as in PRVWPLOT. Table 8 shows a complete list of the control strings for this program. Since most of the control strings have already been described, not all of the available ones will be discussed here.

Table 8. Control strings used by GRDPLOT.

PLOTTER	*PLT_DEVICE*					
FILE-GRD	*DIRECTORY-LOCATION-OF-GRD-DATA-FILES*					
TX-NTR	*TX-FILE-NAME*					
JX-NJR	*JX-FILE-NAME*					
PLOT-LBL	*PLOT-LABEL*					
MAP-AREA	*MAP-ID RECTANGULAR*	*lat1 lon1*	*lat2 lon2*	*size-x size-y*		
MAP-AREA	*MAP-ID MERCATOR*	*lat1 lon1*	*lat2 lon2*	*size-x size-y*		
MAP-AREA	*MAP-ID GNOMONIC*	*lat0 lon0*	*RANGE*	*size-x size-y*		
MAP-AREA	*MAP-ID AZIMUTHAL*	*lat0 lon0*	*RANGE*	*size-x size-y*		
MAP-AREA	*MAP-ID ORTHOGRAPHIC*	*lat0 lon0*	*RANGE*	*size-x size-y*		
MAP-AREA	*MAP-ID STEREOGRAPHIC*	*lat0 lon0*	*RANGE*	*size-x size-y*		
MAP-AREA	*MAP-ID MAP-AREA-SPECIFICATION-FILE-NAME*					
MAP-TYPE	*LAND*					
MAP-TYPE	*COAST*					
MAP-TYPE	*CONDUCTIVITY*					
MAP-TYPE	*COAST LAND*					
MAP-TYPE	*COAST CONDUCTIVITY*					
RX-DATA	*VERTICAL*					
RX-DATA	*HORIZONTAL*					
CNTR-RANGE	*cntr-level-min cntr-level-max cntr-level-inc*					
CNTR-LEVELS	*cntr-level-1 cntr-level-2 ...*					
TA-LEVELS	*ta-level-1 ta-level-2 ...*					
A-NOISE	*NOISE-MODEL-NAME MONTH/day/year hour:minute bandw*					
P-NOISE	*mean-platform-noise*					
PLT-N	*set-to-1-to-do-noise-contours*					
PLT-S	*set-to-1-to-do-plots-of-signal-contours*					
PLT-S/N	*set-to-1-to-do-plots-of-S/N-contours*					
PLT-S/J	*jammer-combinations-for-S/J-contours-to-be-generated*					
PLT-S/I	*jammer-combinations-for-S/(N+J)-contours-to-be-generated*					
PLT-J	*jammer-numbers-for-which-jammer-contours-to-be-generated*					
PLT-J/N	*jammer-numbers-for-which-J/N-contours-to-be-generated*					
MODIFY-PWR	*new-power-level*					
RX-MODEL	*RCVR-MODEL-NAME*					
THRESHOLDS	*threshold-1 threshold-2 ...*					
TERMINATOR	*chi1 chi2*					
BRIEF-LABELS						
START						
QUIT						

TX-NTR and **JX-NJR** are used to name the files that contain the operating-area grid data. Although not encoded in the control string, corresponding files with the extension "GRD" must exist. The substring *NTR* carries over from the LWPM to help the user keep things organized, but only one transmitter may be used at a time. Thus, the program does not use the numerical value of *NTR*. However, the numerical value of the substring *NJR* indicates the jammer numbers used in the control strings that start with **PLT-S/J** and **PLT-J/N**, as described later.

FILE-GRD sets the directory path for the coverage grid data files. If not specified, the program uses the directory in which it is being run.

PLOT-LBL allows the user to add a character string to each graph that is generated. The string is the same for all graphs in a particular set and is placed along the bottom of each graph.

RX-DATA is used to specify the field component to be used by GRDPLOT when plotting the grid files. The data string contains either *VERTICAL* or *HORIZONTAL*.

OP-AREA is used to specify the operating area used to create the "GRD" file in a manner identical to that used by LWPM. The "GRD" file used by the program is named by concatenating the name specified by the control strings **TX-NTR** and **JX-NJR** with the AREA-ID.

CNTR-RANGE is used to specify a range of contour levels to be plotted. The data string contains three values: *cntr-min, cntr-max,* and *cntr-inc.* In this case, the contour lines are plotted from the minimum value to the maximum value in evenly spaced increments. The units of the parameters depend on the coverage map being generated; namely, if the contour map is for signal, then *cntr-min, cntr-max,* and *cntr-inc* are in dB above 1 μV/m; if for signal-to-noise ratio, then they are dB. The contour levels are plotted as color-filled bands using the eight colors specified in the "GRAPHICS.INI" file described below.

CNTR-LEVELS is used to specify a list of up to nine specific contour levels to be plotted. The units of the levels depend on the coverage map being generated; namely, if the contour map is for signal, then *cntr-min, cntr-max,* and *cntr-inc* are in dB above 1 μV/m; if for signal-to-noise ratio, then they are dB. The contour levels are plotted as color-filled bands using the eight colors specified in the "GRAPHICS.INI" file. The list of contour levels is processed as sequential pairs so that at least two values must be specified.

RX-MODEL identifies the model of receiver performance to be used. As already described, there are two receiver models. One of these was developed by PSR and is identified as *PSR*. The other model was developed by MITRE and is identified as *MITRE*.

TA-LEVELS is used to specify up to three time availabilities for which separate coverage maps are to be generated. These levels represent the percentage of time that a signal or signal-to-noise ratio is exceeded.

THRESHOLDS is used to specify up to seven values for time availability contours. These levels are in the units appropriate for the contours being plotted. For example, if the threshold is for signal, then the units are dB above 1 μV/m; if for signal-to-noise ratio, then the units are dB. If **THRESH-OLDS** are specified, then contours of time availability are automatically selected.

A-NOISE is used to specify the parameters of the atmospheric noise to be used to generate contour maps of signal-to-noise ratio and signal-to-interference ratio. The parameters supplied in the data string are used to find the appropriate grid data file that is assumed to exist. The extension of the noise grid data file indicates the name of the noise model: "NTI" is for the NTIA model, "ITS" is for the ITSN model, and "LNP" is for the LNP model. The full name of this file will be formed by concatenating the root file name defined by **TX-NTR** or **JX-NJR** and *AREA-ID*. For example, if *ROOT-FILE-NAME* is *Cutler* and *AREA-ID* is *Atlantic*, then the program looks for a noise grid file named "CutlerAtlantic.NTI", "CutlerAtlantic.ITS", or "CutlerAtlantic.LNP".

P-NOISE is used to specify the mean level in dB of a source of interference other than atmospheric noise. This interference level is treated as a noise floor in that it becomes important as the atmospheric noise approaches the level of the interference. Since the source of this interference is assumed to be man-made, there is no standard deviation associated with it.

The control strings that start with **PLT-** determine the number and type of contour plots produced in a run. The data strings **PLT-S, PLT-N**, and **PLT-S/N** have numerical inputs of one or zero, to turn on or to turn off plotting a corresponding map of contours of signal, noise, and signal-to-noise ratio. The data string of **PLT-J** is a list of jammer numbers for which contour maps of signal level are to be made by using the designated jammers. The jammer numbers are taken from the *NJR* substring of the control string **JX-NJR**. If only one jammer is used, then either **JX** or **JX-1** can be used. Similarly, the data string for **PLT-J/N** identifies the transmitters for which jammer-to-noise contours are to be made. The list of jammers does not have to be the same as used in the **PLT-J** control string.

The control string **PLT-S/J** sets up contour maps of signal-to-jam ratio. The data string associated with this control string can be much more complicated than those associated with **PLT-S** and **PLT-S/N** because this data string contains a list of combinations of jammers. For example, if three jammers have been identified, then the data string can contain any of the following: 1, 2, 3, 12, 13, 23, and 123, indicating contours of signal-to-jammer 1, signal-to-jammer 2, signal-to-jammer 3, signal-to-the sum of jammers 1 and 2, and so on. Similarly, the data string associated with the control string **PLT-S/I** is also a list of combinations of jammers. This control string generates contours of the ratio of signal-to-jammer plus atmospheric noise.

Figure 20 illustrates a sample input file for GRDPLOT using multiple jammers. The file containing the transmitter signal data is in a file named "XMTR.GRD", and those of the jammers are in files named "JAMR1.GRD", "JAMR2.GRD", and "JAMR3.GRD." These files are introduced to the program by using the control strings **TX, JX-1, JX-2**, and **JX-3**, respectively. The **PLT-** control strings call for signal-strength plots for the transmitter and the second jammer. In addition, plots of the ratio of signal-to-jam for jammer 1 and the sum of jammers 1 and 3 are to be done. The **CNTR-RANGE** control string indicates that the range of contours is to be selected from the data and that the increment between levels is 3 dB.

```
op-area      test -10 40 30 -50
map-area     test rect -10 40 30 -50 4 5
map-type     coast
a-noise      ntia jul/15/88 18:00 1000
tx           xmtr
jx-1         jamr1
jx-2         jamr2
jx-3         jamr3
cntr-range   ,,3
ta-levels    50
plt-s        1
plt-j        2
plt-s/j      1 13
start
quit
```

Figure 20. Sample case for multiple jammers in GRDPLOT.

FILE SUMMARIES

The program named SCAN provides summaries of the contents of the output files of the LWPC. The program provides different levels of output depending on the user's specification. The program is set up to interactively get the names of the files to be scanned. However, it can be started with a

command line entry identifying the name of an input file. This is illustrated in the sample case named SCAN. If the file to be scanned has the extension "MDS", there are two levels of printout. The lowest level of output is a summary of the transmitter, op area, and the bearing angles; and lengths and segmentation of all the paths. The next level of output adds the mode parameters at each segment of every path. If the file to be scanned has the extension "LWF", there are three levels of output. The lowest level is a summary of the transmitter, op area, and the bearing angles; and lengths of every path. The next level adds the signal strength and relative phase along every path. The third level of printout only provides the signal strength and relative phase at the receiver coordinates. This output only makes sense if the propagation paths are specified using the **RECEIVERS** and **+RECEIVERS** control strings. If the file to be scanned has the extension "GRD", "NTI", "ITS", or "LNP", there is only one level of printout. This output shows the transmitter, op area, grid coordinates, and dimensions.

Every file written by the programs of the LWPC contain three unique records. Every level of output provided by SCAN shows these records, identified by the string "file id". In an "MDS" file, only the first record is defined. In an "LWF" file, the first two records are defined. In a "GRD", "NTI", "ITS", and "LNP" file, all three records are defined. Figure 21 shows an example of these three records, taken from a "GRD" file. The first record identifies the "MDS" file from which the "LWF" and "GRD" files were generated. The first entry in this record contains the date the file was written. The second entry is a three-character sequence created by a random-number generator using the field for seconds in the time of day as the seed. This entry is unique to the run in which the data are generated. Hence, if the series of data files from "MDS" through "GRD" are all created in a single execution of the LWPM, this field will be the same in all three records. The third entry identifies the program used to create the data, and the last entry contains the full filename of the file. These entries are designed to keep track of inconsistencies between the data contained in the files and user-generated labels and identifications, which may change from run to run. The second record in this figure identifies these same quantities in the "LWF" file, and the third record is for the "GRD" files.

```
06Feb98 IWC LWPM-20 c:\aaa\lwpm\baseline\output\lwpm.mds
06Feb98 IWC LWPM-20 c:\aaa\lwpm\baseline\output\lwpm.lwf
06Feb98 IWC LWPM-20 c:\aaa\lwpm\baseline\output\lwpmmediterranean.grd
```

Figure 21. Example of "file id" records.

SAMPLE CASES

The sample cases (table 9) are not meant to be exhaustive tests of the programs, but to be examples of the usage of the various options. These samples are included with the distribution of the software. The primary output files from the LWPC are the ones with extension "MDS", "LWF", and "GRD." These are not included with the distribution because they are unformatted. However, this report shows the graphical output for the cases that may be compared to the user's results. The sample run streams are named with the extension "INP" and the resulting logs are named with the extension "LOG." Command files named with the extension "CMD" appropriate for running the sample cases under OS/2 or Windows NT are also provided. Table 9 lists these sample cases with a brief description of the options being exercised. A few of these cases are discussed in more detail.

Table 9. Sample cases.

GCPATH   Exercises the program LWPM with the **GCPATH** option and tests the
          control strings: **RECEIVERS** and **+RECEIVERS**. It also verifies that
          the ground-conductivity map is properly installed.

PRVWPLOT Exercises the program PRVWPLOT. Its successful execution verifies
          that the ground-conductivity and coastal-outline maps are prop-
          erly installed.

LWPM   Exercises the program LWPM with the **OP-AREA** option. This run will
          take some time but it is necessary to set up the test of GRDPLOT.

GRDPLOT   Exercises the program GRDPLOT for the data created by the sample
          case named LWPM.

BEARINGS Exercises the program LWPM with the **BEARINGS** and **+BEARINGS**
          options with a specific date and time chosen to put the day-night
          terminator on the path.

LWFPLOT   Exercises the program LWFPLOT using the data created by the sam-
          ple case named BEARINGS.

LWFLDS   Exercises the program LWPM with the **LWFLDS** option using the data
          generated by the sample case named BEARINGS.

HTABLE   Exercises the program LWPM with the horizontal tabular ionosphere
          option.

REXP   Exercises the program LWPM with the range-dependent exponential
          ionosphere option. The variation of the exponential profile
          matches that used in the sample cases named BEARINGS along the
          path at a bearing of 24°.

RTABLE   Exercises the program LWPM with the range-dependent tabular iono-
          sphere option.

CHIEXP   Exercises the program LWPM with the solar-zenith-angle-dependent
          exponential ionosphere option.

SCAN   Exercises the program SCAN on the outputs from several of the
          other sample cases.

PRVWPLOT

The program named PRVWPLOT shows the propagation paths used in a case. Figure 22 shows the run stream used for making the preview plot. The resulting display is shown in figure 23.

```
Select output device
plotter      sys-scn
  plotter      sys-prn
  plotter      prvwPlot.hgl
case-id      OMEGA coverage of the Mediterranean
tx           lwpm
tx-data      OMEGA-D
ionosphere   lwpm Apr/08/97 06:30
op-area      Mediterranean  30    10   45   -45
map-type     conductivity
map-area     N_Atlant rect   0   100   90   -40   7   4
start
quit
```

Figure 22. Input data file for sample case PRVWPLOT.

Rectangular from (0N 100W) to (90N 40E)
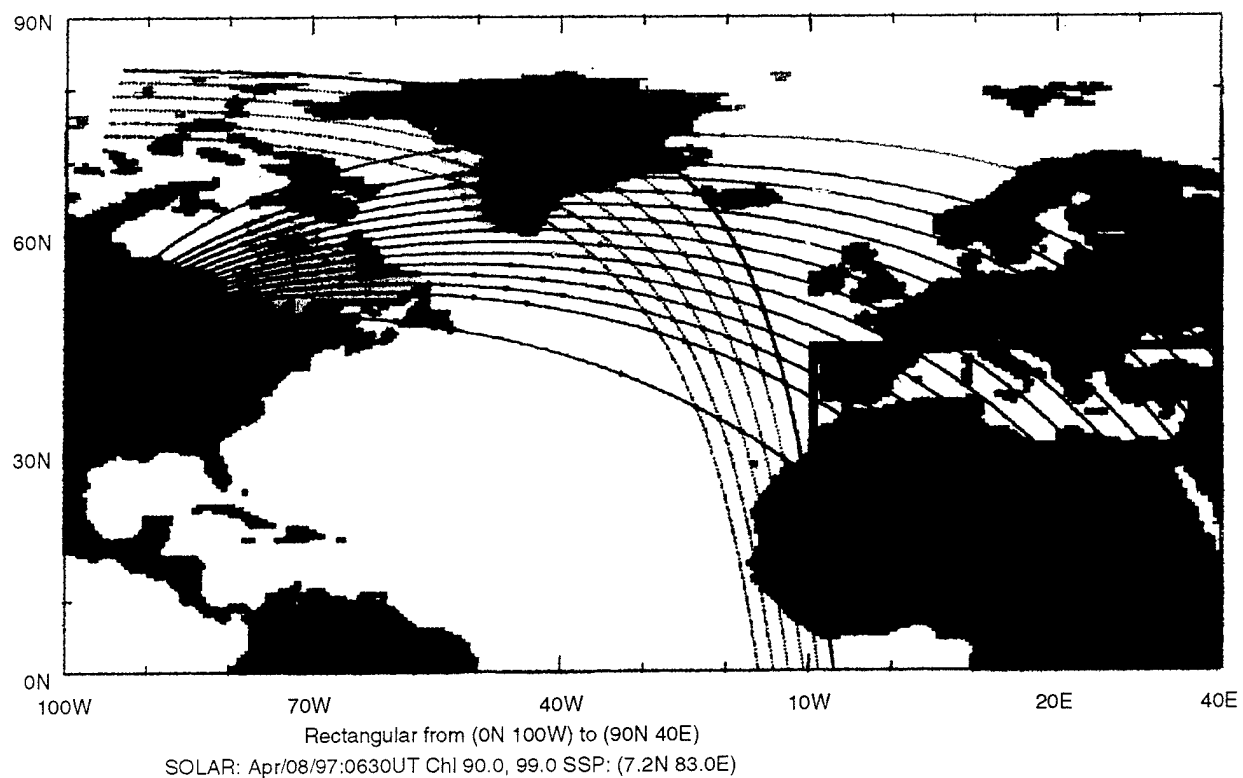SOLAR: Apr/08/97:0630UT Chl 90.0, 99.0 SSP: (7.2N 83.0E)

Figure 23. Graphical output for sample case PRVWPLOT.

LWPM

Figure 24 shows the basic run stream LWPM. The transmitter parameters are retrieved from the default transmitter specification file using the transmitter name OMEGA-D. An operating area named Mediterranean is used to define the propagation paths. The root file name is LWPM so that the following files are created:

"LWPM.MDS", "LWPM.LWF", and "LWPMMEDITERRANEAN.GRD".

```
case-id      OMEGA coverage of the Mediterranean
  Name the files
tx           lwpm
  Identify the transmitter
tx-data      OMEGA-D
  Choose the LWPM model daytime environment
ionosphere  lwpm day
  Define the operating area
op-area      Mediterranean 30 10 45 -45
  Calculate atmospheric noise using NTIA in July at 1800 UT
a-noise      ntia July 18 1000
start
quit
```

Figure 24. Input file for sample case LWPM.

The scenario defined in figure 24 is the basis for most of the other sample problems. For example, the propagation paths specified in BEARINGS are chosen from the set generated in this case. This sample case must be run to generate the data sets required by several of the other cases listed in table 9.

GRDPLOT

The sample case named GRDPLOT, shown in figure 25, generates the plots of contours of constant signal strength and signal-to-atmospheric-noise ratio over the Mediterranean operating area defined by the sample case named LWPM. The contours in figure 26 are for the signal-to-atmospheric-noise ratio at 90% time availability. The rapid drop in signal-to-noise ratio as propagation paths cross Greenland is seen in the closely spaced and nearly vertical contour lines in the eastern part of the operating area.

```
Select output device
plotter      sys-scn
 plotter      sys-prn
 plotter      grdPlot.hgl

plot-lbl     OMEGA North Dakota in the Mediterranean Sea
 Specify location of GRD files
file-grd     Output\
  Name the files
tx           lwpm
  Choose the vertical fields
rx-data      vertical
  Define the operating area
op-area      Mediterranean      30 10 45 -45
  Define the map area
map-area     Mediterranean rect 30 10 45 -45 7 4
  Choose the land delineation
map-type     land coast
  Use the atmospheric noise for the NTIA model in July at 1800 UT
a-noise      ntia Jul 18 1000
  Use the default contour range with 3 dB increments
cntr-range   ,,3
  Use time availabilities of 50% and 90%
ta-level     90
  Turn on  plot of the signal
plt-s        1
start
  Turn off plot of the signal
plt-s        0
  Turn on  plot of the signal to noise ratio
plt-s/n      1
start
```

Figure 25. Input file for sample case GRDPLOT.

Tx 1:omega-d   10.2 46:22N 98:20W 10   0   0   0   Ionosphere   FILE

Noise:ntia   10.2 Jul 1800UT   LWPM Day   18 Feb98 DXR LWPM 2.0 c:\lwpcv20\output\lwpmmediterranean.grd

                                                                                18 Feb98 DXR LWPM 2.0 c:\lwpcv20\output\lwpmmediterranean.nti

Rx: E Alt Bandw Depth
   km Hz ft
V 0 1000 0

90% availability

S/N (d/B)		% 0
−60.0	to −57.0	85
−57.0	to −54.0	81
−54.0	to −51.0	75
−51.0	to −48.0	71
−48.0	to −45.0	66
−45.0	to −42.0	57
−42.0	to −39.0	49
−39.0	to −36.0	25
−36.0	to −33.0	13
−33.0	to −30.0	2
−30.0	to −27.0	0

Rectangular from (30N 10W) to (45N 45E)
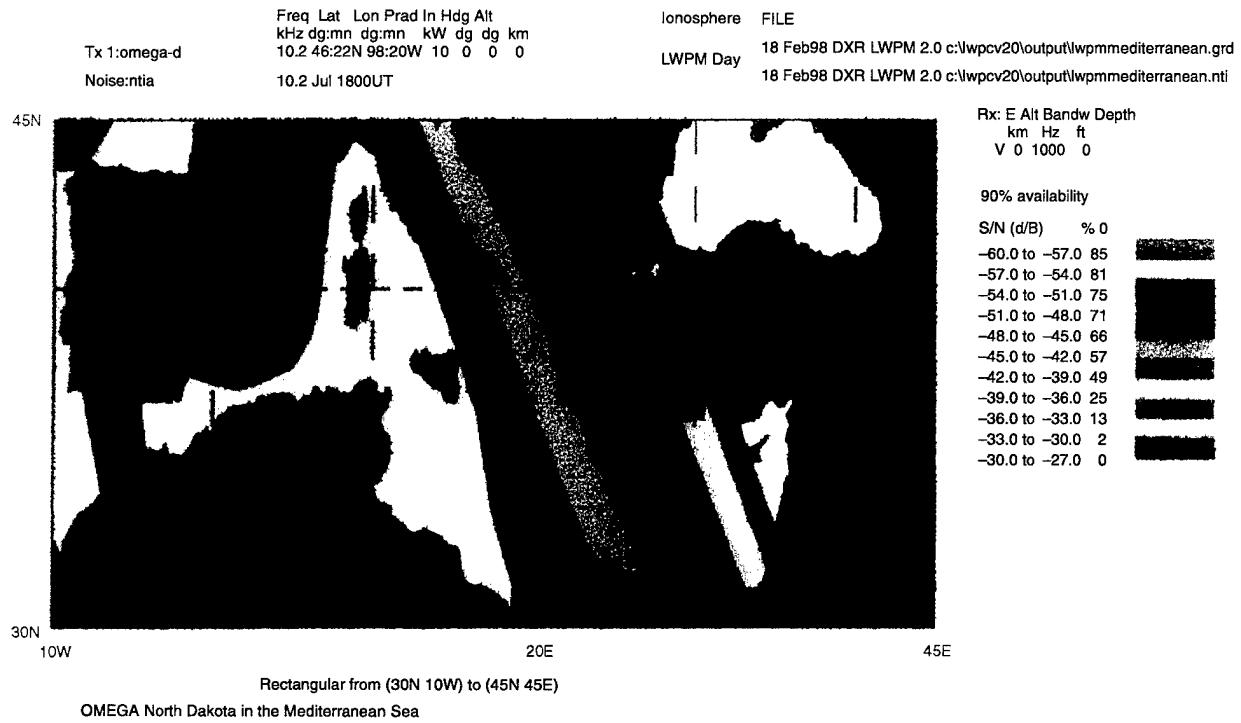
OMEGA North Dakota in the Mediterranean Sea

Figure 26. Plotted output from sample case GRDPLOT.

BEARINGS

The basic case shown in figure 23 can take a long time to run. The case set up by BEARINGS, shown in figure 27, generates data for a subset of this case using three of the paths shown in figure 23. However, the ionospheric model is *LWPM* with a specific date and time.

```
case-id      OMEGA coverage of the Mediterranean
  Name the output files
tx           bearings
  Identify the transmitter
tx-data      OMEGA-D
  Choose date and time
ionosphere   lwpm Apr/15 22:00
  Set maximum range of paths
range-max    11000
  Choose bearings angles at 24, 48 and 72
bearings     24 48
+bearings    72
  Get extra print out from the mode generation
print-swg    2
  Set the maximum range for the fields at 5000 km
lwf-vs-dist 5000
  Get extra print out from the mode summation
print-lwf    2
start
quit
```

Figure 27. Input file for sample case BEARINGS.

LWFPLOT

The program LWFPLOT is exercised by the sample run stream LWFPLOT to produce the plots of signal *versus* distance shown in figure 28. This figure shows the signal strength as a function of distance from the transmitter along the path making a bearing of 48°. Along the bottom of the graph is a summary of the important path segmentation data, namely, the height of the ionosphere and the ground conductivity. The beginning of each segment is indicated by a small symbol in the curve representing the ground conductivity.
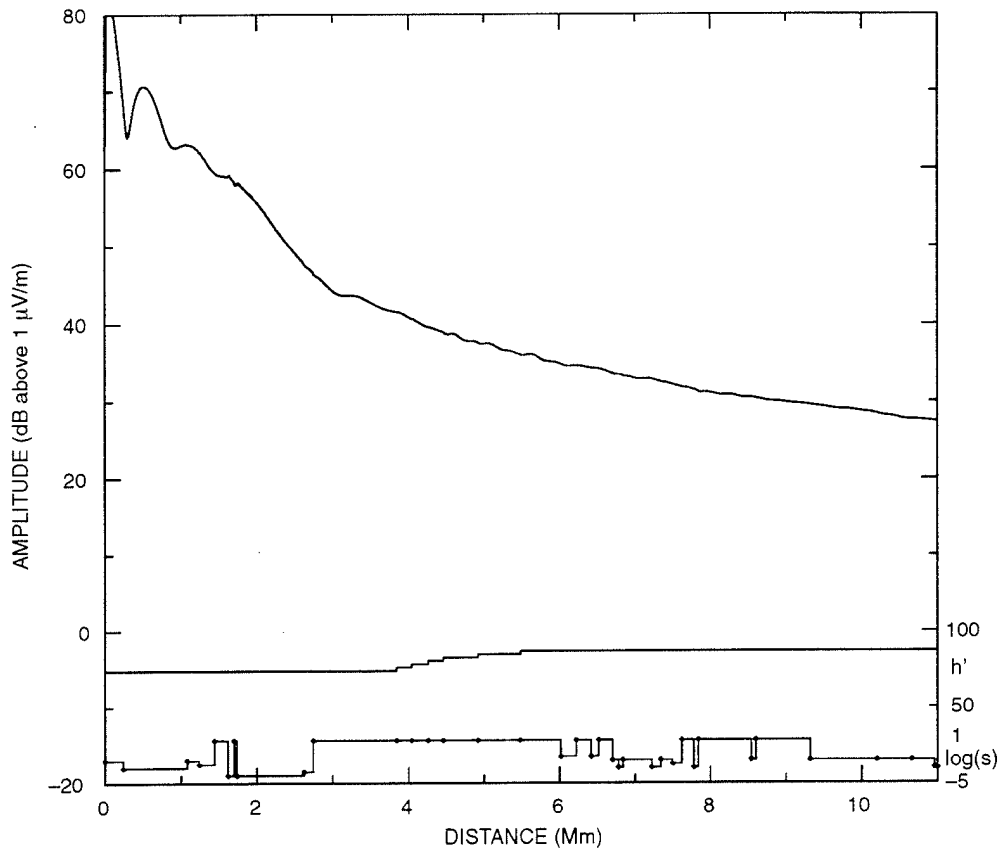
OMEGA coverage of the Mediterranean
xmtr_id freq tlat tlon brng pwr in hdg talt ralt
omega-d 10.2 46.4 98.3 48.0 10 0 0.0 0.0 0.0
Prfl: LWPM Date: 04/15/84:2200
File: 17Feb98 TKM LWPM-20 c:\lwpcv20\output\bearings.mds
File: 17Feb98 TKM LWPM-20 c:\lwpcv20\output\bearings.lwf
Prgm: LWPM-20

Figure 28. Plotted output from sample case LWFPLOT.

LWPC DATA FILES

The LWPC requires a number of data files for its execution. These files contain geophysical information such as ground conductivity, coastal outline coordinates, and coefficients for the atmospheric noise. The program also requires a file for graphical initialization and specification of transmitter coordinates and map area boundaries. These files must all be located in a common directory, typically named "LWPC_DAT" or "LWPC\Data".

LWPC DATA LOCATION

A file named "lwpcDAT.loc" must be placed at the root of drive C. There is no case sensitivity in the file name on computers running OS/2 or Windows 95/NT so the name as shown is just a matter of style or taste. This file contains only one record identifying the path to the LWPC data files. Using one of the above examples, this record would look like "C:\LWPC\Data\" if it referred to a directory named "\LWPC\Data\" on drive C.

GEOPHYSICAL DATA

The ground-conductivity map is stored in a text file named "COND$D.DAT" and in a binary file named "COND$F.DAT. The program uses the text file to specify the ground conductivity. The program uses the binary file to display the ground-conductivity areas graphically. The coastal outline database is contained in a binary file named "COAST$D.DAT". The coefficients used to calculate the levels of atmospheric noise are stored in the binary files named "ITSN$D.DAT" for the ITSN model and in "NTIA$D.DAT" for the NTIA model.

TRANSMITTER AND MAP SPECIFICATION

The user has two methods of setting parameters associated with the control strings **TX-DATA, JX-DATA, OP-AREA**, and **MAP-AREA.** If the user specifies the parameters of the control string explicitly in the data string, then the corresponding specification file found in the directory containing the LWPC data files is updated by using the new values. If the specification file already contains an entry with the same identification as used by the user, the parameters in the file are compared with the values supplied by the user. With one exception, if every value specified by the user does not match those found in the specification file, then the run is aborted. This is done to require a consistent naming convention for transmitters, operating areas, and map areas. The exception noted above is for **MAP-AREA.** The user may change the dimensions. The user can edit the specification files to clean them up and remove entries as required. These files must be located in the directory containing the LWPC data files. The transmitter specification file is named "XMTR.LIS", the op-area specification file is named "AREA.LIS", and the map-area specification file is named "MAP.LIS".

GRAPHICS INITIALIZATION

The graphical output provided by the LWPC is controlled in part by an initialization file named "GRAPHICS.INI". Figure 29 is a sample of this file. This file identifies colors and fill patterns for contour fill areas and geophysical displays. There are two sections in this file. The first section identifies color assignments and is preceded by a control string "colors" and terminated by a control string "end". Similarly, the second section is demarked by the strings "fills" and "end". The order of these sections may be reversed within the file. The records containing the string "colors" and "fills" may contain additional identification as illustrated in the figure. Each record in the colors section must contain the following data: name of the color, the red-green-blue (RGB) sequence used to define the color, and a pen number.

```
colors:       r   g   b   pen notes
labels      000 000 000   1  The 1st 8 colors are defined for the
red         255 000 000   2  default PowerPoint assignments for HPGL
green       000 255 000   3  importation.
yellow      255 255 000   4
blue        000 000 255   5
purple      255 155 205   6
cyan        000 255 255   7
black       000 000 000   8              .
coast       000 000 000   1
land        000 127 000   3
border      000 000 000   1
grid        000 000 255   1
oparea      255 155 205   1
terminator  000 000 255   5
color1      180 000 000   2  darkRed
color2      000 128 128   4  darkCyan
color3      000 000 171   5  Blue
color4      255 255 128   6  paleYellow
color5      255 000 000   7  Red
color6      128 000 128   8  Purple
color7      255 128 128   2  Salmon
color8      000 000 100   3  darkBlue
end
fills:      name
fill01        2%
fill02       10%
fill03       20%
fill04       35%
fill05       55%
fill06       80%
fill07       99%
fill08      100%
fill09      horizontalLines
fill10      verticalLines
fill11      leftDiagonalLines
fill12      rightDiagonalLines
end
```

Figure 29. Sample graphics initialization file.

The programs of the LWPC fix the names of the colors. However, the user may change the color displayed by changing the RGB sequence to suit individual taste. For example, a lighter shade of green could be displayed by changing the RGB sequence for "green" to 000 125 000. The pen number is written to the HPGL output files in place of the color or RGB sequence. Importing HPGL files into PowerPoint only allows specification of pen numbers to identify colors, and the maximum number of pens (colors) is eight. The colors named "coast", "land", "border", "grid", "oparea", and "terminator" are used for the corresponding display in the graphical output. The colors named "colorN", where "N" is 1 through 8, are used in numerical order to color the contour plots generated by "GRDPLOT". If the file provided with the software distribution is modified, care should be taken to ensure that the pen numbers assigned to these eight colors do not match the one used for the landmass overlay.

OUTPUT DATA FILES

The output files are all written in unformatted form and a special program named SCAN is used to print out summaries of the parameters that are stored in them. Some parameters share common usage throughout the full set of output data files. Whenever appropriate, the parameters from one file are passed on to subsequent types of files to provide continuity and some audit-trail information. The first record of all data file types contains the same information. The first record contains an eight-character string to be used to record archive information. This record also contains three strings, named *MDS-FILE-ID, LWF-FILE-ID,* and *GRD-FILE-ID.* Each of these strings contains the date the file was written; a randomly generated, three-character string to uniquely identify the file; and the full file name, including the directory tree. The presence of these strings in each type of file provides information regarding the history of the data used to produce the file. For instance, each "GRD" file identifies the "LWF" file that provided the signal strength data and the "MDS" file that provided the "MDS" data used to calculate the "LWF" data. The program identification will be *LWPM–V20.* The first record also contains a list of parameters to identify the propagation paths for the data sets. The character string *PATH-ID* contains the *AREA-ID* if the paths were defined with an **OP-AREA** control string, *Bearings* if the paths were defined with the **BEARINGS** control string, and *Receivers* if the paths were defined with the **RECEIVERS** control string. If the **RECEIVERS** control string was used, then the list of receiver coordinates is stored in the arrays *rxlat* and *rxlon.* If the **OP-AREA** control string was used, then the lengths of the paths are stored in the array *range;* otherwise, the array *range* stores the constant value specified by the control string **RANGE-MAX.** Also, if the control string **OP-AREA** was used, then the boundaries of the operating area are stored in this first record.

Figure 30 shows the data written to the "MDS" files. Character strings are shown in uppercase, and the length of each string is shown in brackets following the name of the string. Record 2 identifies the parameters of each segment of each path, beginning with the geographical bearing angle (*brng*), the length of the path (*rhomax*), the receiver coordinates (*rlat, rlon*), and the range to the receiver (*rrho*). Additional parameters are stored in the array *param1.* Currently, this array contains 10 parameters: the coordinates of the beginning of the segment (*lat, lon*), the range from the transmitter to the beginning of the segment (*rho*), the orientation and strength of the geomagnetic field with respect to the direction of propagation (*azim, dip, magfld*), the ground conductivity and dielectric constant (*sigma, epsr*), and the slope and reference height of the exponential ionosphere (*beta, hprime*). Record 3 contains the eigen angle of the mode and the following five parameters stored in the array *param2:* T1, T2, T3, T4, f(R) (Ferguson and Snyder, 1980). The end of segment data for each path is indicated by a dummy record containing: *brng, rhomax, rlat, rlon, rrho, 0, 1, 0, 99.* Records 2 and 3 are repeated for each path.

```
Record:
1       ARCHIVE[8],
        MDS-FILE-ID[120],
        LWF-FILE-ID[120],
        GRD-FILE-ID[120],
        PRGM-ID[8],
        CASE-ID[80],
        PRFL-ID[40],
        XMTR-ID[20],freq,txlat,txlon,
        PATH-ID[20],nrpath,
        op-lat1,op-lon1,op-lat2,op-lon2,
        (bearing(i),range(i),rxlat(i),rxlon(i),i=1,nrpath)
2       brng,rhomax,rlat,rlon,rrho,nprm1,nrmode,nprm2,
        (param1(i),i=1,nprm1)
3       (eigen(m),(param2(i,m),i=1,nprm2),m=1,nrmode)
```

Figure 30. Order of data parameters in "MDS" files.

Figure 31 summarizes the output written to "LWF" files. Record 2 contains a summary of the parameters along each path. The array *sgmnt* stores the path segmentation data for each path in the data set. At present, the number of parameters stored in *sgmnt* is stored in *nrps,* and the number of segments is stored in *nrsgmnt.* The array *sgmnt* contains the following 10 parameters: the coordinates of the beginning of each segment (*lat, lon*), the range from the transmitter to the beginning of the segment (*rho*), the orientation and strength of the geomagnetic field with respect to the direction of propagation (*azim, dip, magfld*), the ground conductivity and dielectric constant (*sigma, epsr*), and the slope and reference height of the exponential ionosphere (*beta, hprime*). If nonexponential profiles are used, an eleventh parameter showing the profile index is added. The number of points at which the signal strength and relative phase are computed is stored in *nrpt1.* The signal strength and relative phase along each path is calculated parametric in the following seven parameters: the number of field components (*nrcmp*), the transmitter power (*power*), the distance from the transmitter (*dist*), the orientation of the antenna (*inclination, heading*), and the altitude of the transmitter and the receiver (*talt, ralt*). The parameter *dist* is not used in LWPC-2.0; it is included for compatibility with a planned extension of the mode summing capability. The values of these parameters, excluding *nrcmp,* are stored in the array *param.* The number of such parametric records determines the number of signal-strength arrays written to the file. The number of these records is stored in *nrpt2.* Record 3 stores the distance, signal strength, and phase relative to the propagation in free space. The array *xy* stores the distances from the transmitter at which signal strength and relative phase are computed; *amp* stores the signal strength in dB above $1\mu V/m$; and *phs* stores the relative phase. Record 3 is repeated as required by the value of *nrcmp* and *nrpt2* (in LWPC-2.0, *nrpt2* is always 1). Records 2 and 3 are repeated for each path.

```
Record:
1       ARCHIVE[8],
        MDS-FILE-ID[120],
        LWF-FILE-ID[120],
        GRD-FILE-ID[120],
        PRGM-ID[8],
        CASE-ID[80],
        PRFL-ID[40],
        XMTR-ID[20],freq,txlat,txlon,
        PATH-ID[20],nrpath,
        op-lat1,op-lon1,op-lat2,op-lon2,
        (bearing(i),range(i),rxlat(i),rxlon(i),i=1,nrpath)
2       brng,rhomax,rlat,rlon,rrho,nrps,nrsgmnt,
        nrprm,nrpt1,nrcmp,nrpt2,((sgmnt(i,j),i=1,nps),j=1,nsgmnt)
3       (param(i),i=1,nprm),
        (xy(i),amp(i),phs(i),i=1,nrpt1)
```

Figure 31. Order of data parameters in "LWF" files.

Figure 32 summarizes the data written to the "GRD" files. The parameters *nrcmp* and *nrpt2* are carried over from the "LWF" file. Record 2 identifies the operating area and its boundaries (*AREA-ID, xlat1, xlon1, xlat2, xlon2*) and the number of points in the grid in longitude (*nrlon*) and latitude (*nrlat*). The grids of signal strength and associated standard deviation of the signal are written parametric in the same set of parameters used for the "LWF" files. Consequently, record 3 is repeated as required by the values of *nrcmp* and *nrpt2* (in LWPC-2.0, nrpt2 is always 1). Records 2 through 3 are repeated for each operating area. The array *param* stores the parameters of the grid data: the transmitter power (*power*), the distance from the transmitter (*dist*), the orientation of the transmitting antenna (*inclination, heading*), the altitude of the transmitter and the receiver (*talt, ralt*), the date and time (*MONTH, day, year, UT*), the bandwidth (*bandw*), the adjustment factor for horizontal noise (*adjny*), and the standard deviation of the signal (*stndev*). Furthermore, if the "GRD" file is for atmospheric noise, then *CASE-ID* contains the string *Noise*; *XMTR-ID* contains the name of the noise model and the date and time used to compute the values of atmospheric noise.

```
Record:
1       ARCHIVE[8],
        MDS-FILE-ID[120],
        LWF-FILE-ID[120],
        GRD-FILE-ID[120],
        PRGM-ID[8],
        CASE-ID[80],
        PRFL-ID[40],
        XMTR-ID[20],freq,txlat,txlon,
        PATH-ID[20],nrpath,
        op-lat1,op-lon1,op-lat2,op-lon2,
        (bearing(i),range(i),rxlat(i),rxlon(i),i=1,nrpath)
2       area-id[20],xlat1,xlon1,xlat2,xlon2,nrlon,nrlat,
        nrprm,nrcmp,nrpt2
3       (param(i),i=1,nprm),
        ((amplitude(i,j),sigma(i,j),i=1,nx),j=1,ny)
```

Figure 32. Order of data parameters in "GRD" files.

SOFTWARE INSTALLATION

The source-code files and data files are distributed in three zip files (lwpcv20, lwpcData, baseline) that fit on two standard 1440-kilobyte, 3.5-inch floppy diskettes. To obtain a copy of these files, contact Jerry Ferguson (e-mail: ferguson@spawar.navy.mil).

For use on computers running Windows NT*, the executable program files and binary data files are distributed in three other zip files (lwpcExe, lwpcDat, lwpcPlt) that fit on two standard 1440-kilobyte, 3.5-inch floppy diskettes.

Create a directory to contain the LWPC files, assumed to be "C:\LWPCv20\". Copy the distribution files into this directory and execute the file "Startup.cmd" to unpack the files.

If the LWPC files are placed in a directory *not* named "C:\LWPCv20\", then edit the file named "setLWPC.cmd" to show the correct path.

Execute the file "BuildLWPC.cmd" to create the library, binary data files, and executable files.

If the executable files and the binary data files are to be used as provided in the software distribution, copy the zip files from the diskettes into the LWPC directory. Execute the file named "Binary.cmd" to unpack the files.

The LWPC data files are placed in a subdirectory named "Data". If these files are placed in a directory *not* named "C:\LWPCv20\Data\", edit the file named "lwpcDAT.loc" to show the correct path and copy it to the root directory of drive C.

Execute the sample cases to verify the correct installation.

The subdirectory named "C:\LWPCv20\Baseline\" contains backup copies of the sample cases and the resulting output. The files in this directory should not be modified in any way.

OPERATING SYSTEM AND COMPILER

The programs of the LWPC as distributed are written for the Windows NT® operating system and the WATCOM C and FORTRAN compilers. The routines written in C provide the graphical interface between the FORTRAN routines and the screen and printer. In the subdirectory named Library, these routines all have names that begin with "sys_". The FORTRAN routines whose names end with the string "Plot" are really subroutines to the graphics driver named "GRFDriver", which is written in C, found in the subdirectory named GRFDriver. The compiler flags and linking options can be found in the file named "BuildLWPC.cmd", which is executed to create the programs from the source files. Finally, the following routines are used to make compiler-specific calls to obtain system-dependent parameters: get_command_line.for, get_date.for, get_random.for, and get_time.for.

---

* Windows NT is a registered trademark of Microsoft Corporation.

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This document describes a revision of the Navy's Long-Wavelength Propagation Capability (LWPC) developed by the Space and Naval Warfare Systems Center, San Diego. This version of the program includes improvements to the graphics routines, increased flexibility in specification of alternative ionospheric models, and an option to execute a full-wave mode conversion model for the signal-strength calculations. This version is principally composed of FORTRAN subroutines with a few additional routines written in C to implement the graphics capabilities under the Windows 95/NT operating systems.

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