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STATUS OF THE NAVAL OCEAN SYSTEMS CENTER'S LONG WAVE PROPAGATION CAPABILITY

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INTRODUCTION

This paper describes a new software version of the Naval Ocean Systems Center's Long Wavelength Propagation Capability (LWPC). This program applies the concept of the earth-ionosphere waveguide to very low frequency (vlf: 10 kHz to 30 kHz) and low frequency (lf: 30 kHz to 60 kHz) radio propagation. The propagation capability has been incorporated into a FORTRAN program which sets up calculation of mode parameters along arbitrary propagation paths or for user defined operating areas. In the latter case, the paths are automatically selected to account for areas of low conductivity. Previous dependence on VMS has been eliminated. Substantial improvements have been made in storage and identification of the program outputs. A set of programs have been developed for graphically displaying the output from the program.

The first version of the LWPC was a collection of separate FORTRAN programs linked together in operation by a command procedure written in Digital Equipment Corporation's VMS operating system command language (Ferguson and Snyder, 1989a,b). The initial version, designated LWPC-0 in this paper, was originally a test of a concept, making full integration of the constituent programs premature. The core of the new LWPC, designated LWPC-1, is embodied in a single FORTRAN program named LWPM (short for Long Wavelength Propagation Model). This program implements all of the features of the original VMS version. In addition, LWPC-1 includes a number of auxiliary FORTRAN programs which provide summaries of the contents of files and can be used to update and graphically display the contents of its output files.

The propagation model implemented in the LWPC-1, which is identical to that in LWPC-0, treats the space between the earth's surface and the lower ionosphere as a waveguide. The upper boundary of this waveguide is characterized by an isotropic conductivity which increases exponentially with height. The exponential increase is defined by a log-linear slope and a reference height. The LWPC incorporates a model which defines an average value of the slope and reference height which depends on frequency and diurnal condition. The height of the nighttime ionosphere over the polar caps is lower than it is at middle and equatorial latitudes. This model has been compared extensively with available measurements. The lower boundary of the LWPC is based on the Westinghouse Geophysics Laboratory conductivity map (Morgan, 1968). Both boundaries of the earth-ionosphere waveguide are known to have possibly large uncertainties in certain regions and seasons.

A typical usage of the LWPC is to generate geographical maps of signal availability for coverage analysis. The program makes it easy to set up such problems by automating most of the required steps. The user specifies the transmitter location and frequency, the orientation of the transmitting and receiver antenna and the boundaries of the operating area. The program automatically selects paths using a coarse resolution of 15 degrees to ensure that the operating area is fully covered and then using a fine resolution of 3 degrees to ensure that all significant low conductivity areas are included. 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 and is then mapped onto a grid overlaying the operating area. The data in the grid include a user specified (constant) standard deviation of the signal throughout the grid. The signal strengths in this grid can be displayed by other programs to be described later.

LWPC-1 incorporates a number of improvements over LWPC-0 including reduced dependence on the operating system, better integration of the intermediate data storage and modification of the input to use control strings coupled with input parameters. An option for previewing the propagation paths to be processed by the program is included. A map with major land masses graphically filled is included in this preview option as well as in the geographical coverage displays. The main program, LWPM, incorporates essential elements of several of the programs used in LWPC-0: PRESEG (which sets up the paths), MODEFNDR (which determines the initial solutions for each set of segments), the Segmented Waveguide program (which determines the solutions for segments of similar type), FASTMC (which does the mode summation along the path) and OPAREA (which sets up the data for plotting coverage area maps). While LWPC-0 generates a log file and a mode parameter data file for each path which is processed, LWPC-1 generates only one log file and one data file, making file management easier.

Three noise models are currently available: 'ITSN' names the ITS noise model of Zacharisen and Jones (1970), 'NTIA' names the noise model of Spaulding and Washburn (1985) and 'DECO' names the DECO Westinghouse thunderstorm-based noise model (Maxwell et al., 1970). The NTIA model is identical to the new CCIR noise model (CCIR, 1986). The model named ITSN is the implementation of CCIR 322 (CCIR, 1963) which maps the basic noise map parameter, Fam, in Universal Time. The model named NTIA is the new noise model developed 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 DECO model of atmospheric noise is limited to the VLF regime (10 to 30 kHz) and uses a data base of thunderstorms and does propagation calculations from these thunderstorms to the receiver sites. This model was calibrated using the same measurement sites which were used to develop the other two models. Because the model uses propagation calculations instead of polynomials, it is a much longer running model and is used infrequently.

PROGRAM CONTROL

The LWPC-1 uses character strings for program control and to specify options. The control strings have the same meaning and use amongst all of the programs. On input, most control strings may be abreviated. 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 which are composed of more than one word, dashes are used to separate the words, such as the above mentioned "TX-DATA". A blank in the first column 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.

After the necessary control strings and their associated data are specified, a specific control string named "START" is used to initiate the calculations. The program LWPM first creates a status file. This file is named with the extension STA and contains a list of the bearing angles and lengths of all of the paths. As the calculation of mode parameters along each path is completed, the parameters are written to a file named with the extension MDS and the corresponding entry in the status file is updated with the date and time of completion and the CPU time used. Calculations for successive paths continues automatically. If the computer run aborts for some reason, then the run can be restarted simply by resubmitting the original command file, after the error has been corrected. The program checks for the existence of the status file and continues execution at the first entry which does not have a date and time entry. 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 and the status file is updated. If the propagation paths were 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 and the status file is updated. The GRD file contains values of the signal strength and its standard deviation in a grid of latitude vs. longitude which covers the operating area. This last file may now be used in a program named PLOT_GRD to obtain geographical displays of the signal levels, signal to noise levels, or, together with other GRD files, signal to jammer levels.

OUTPUT DATA

An important improvement in LWPC-1 is in the handling of data files. Compared to LWPC-0, more information is stored in these files and the formats have been developed to allow for future enhancements. The new files are all written in unformatted form and a special program named SCAN has been written to print out summaries of the parameters stored in them. Some parameters share common usage throughout the full set of output data files. Whenever appropriate, these parameters from one file are passed on to subsequent types of files in order to provide continuity and some audit trail information. The first record of all data file types contains the same information. This first record contains an 8 character string to be used to record archive information. It 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, 3 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 which was used to produce the file. For instance, each GRD file identifies the LWF file which provided the signal strength data and the MDS file which provided the mode parameter data used to calculate the LWF data. Generally, the program identification will be 'LWPM-V10'. This first record also contains the list of parameters to identify the propagation paths for the data sets.

A utility program named SCAN is used to produce summaries of the data in any of the output files. Examples of the output from this program using the sample problem are shown below.

SAMPLE PROBLEM

To illustrate the capabilities of LWPC-1 a sample case is presented. The run stream is shown in Figure 1. An operating area named "Mediterranean" is used to define the propagation paths. The root file name is "SAMPLE" so that the following files were created: SAMPLE.sta, SAMPLE.mds, SAMPLE.lwf and SAMPLE_mediterranean.grd. The transmitter parameters were retrieved from a specification file. The preview option was exercised to produce the plot shown in Figure 2. A preview option was then "turned off" by indenting the control string one space.

The second execution of the program produced the MDS, LWF and GRD files named above. Figure 3 shows the output from the SCAN program for the first path in the MDS file. The output identifies the program which was used to generate the file and the date that it was run. The data under the heading which begins with "mds" is a summary of the parameters for each segment along the path. Figure 4 shows the output from the SCAN program for the LWF file. The parameter under the heading "nc" identifies the number of field components in the mode sums. The data under the heading which starts with "bearng" identify the paths by their bearing angle and shows the length of each path. The signal strength as a function of distance from the transmitter along the northernmost (bearing = 24 degrees; upper panel) and southernmost (bearing = 72 degrees; lower panel) paths are plotted in Figure 5. Along the bottom of each 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 diamond in the curve representing the ground conductivity. In the northern path, the rapid change in signal strength that occurs near 4 Mm is due to the effect of Greenland.

Figure 6 shows the SCAN output for the GRD file. This output identifies the boundaries of the operating area. The values under the headings "nlat" and "nlon" are the number of latitudes and longitudes used to define the grid. Sample contour maps generated by PLOT_GRD using the run stream in Figure 7 are presented in Figures 8 and 9. The first of these figures shows contours of signal strength and the second shows contours of signal to atmospheric noise ratio. The rapid drop in signal strength as paths cross Greenland is seen in the closely spaced and nearly vertical contour lines in the eastern part of the operating area.

DISTRIBUTION

The source code and associated data sets are available from the Defense Technical Information Center.

REFERENCES

CCIR, World Distribution and Characteristics of Atmospheric Radio Noise, Rept. 322, Documents of the Xth Plenary Assembly, Geneva, 1963.

CCIR, World Distribution and Characteristics of Atmospheric Radio Noise, Rept. 322-3, Documents of the XVIth Plenary Assembly, Geneva, 1986.

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Maxwell, E. L., D. L. Stone, R. D. Croghan, L. Bell, A. D. Watt, Development of a VLF Atmospheric Noise Prediction Model, Westinghouse Georesearch Laboratory Rept. 70-1H1-VLF NO-R1, 1970.

Morgan, R. R., World-wide VLF Effective Conductivity Map, Westinghouse Electric Corp. Rept. 8013F-1, 1968.

Spaulding, A. D., J. S. Washburn, Atmospheric Radio Noise: Worldwide Levels and Other Characteristics, U. S. Dept. of Commerce NTIA Rept. 85-173, 1985.

Zacharisen, D. H., W. B. Jones World Maps of Atmospheric Radio Noise in Universal Time by Numerical Mapping, U. S. Dept. of Commerce, Office of Telecommunications Rept. OT/ITSRR 2, 1970.


```
$ run lwpc-dir:lwpm
case-id      OMEGA coverage of the Mediterranean
tx           SAMPLE
tx-data      OMEGA-D lwp:[dat]xmtr.list
ionosphere   lwpm day
op-area      Mediterranean 30 10 45 -45
lwf-vs-dist  ,11000,,
print-swg    2
print-lwf    2
 gcpath
 preview
map-area     LANT rect 20 100 80 -50 7 5
map-type     conductivity
start
quit
```

Figure 1: Sample run stream for LWPM

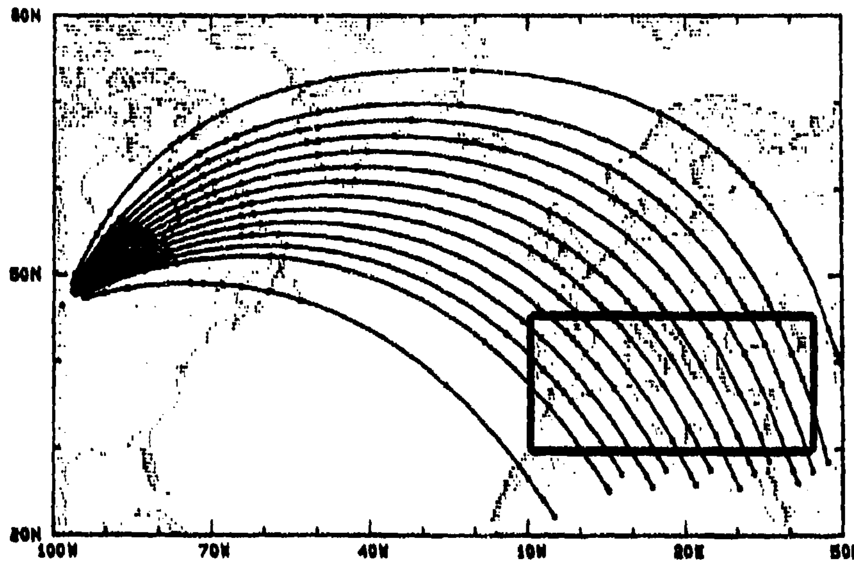

Figure 2: Output from "PREVIEW" option.

```
file_id:   11DEC89 LSF [.lwp.tst]SAMPLE.mds
           ***
           ***
prgm_id:   LWPM-V10
case_id:   OMEGA coverage of the Mediterranean
prfl_id:   LWPM Day
xmtr_id                  tlat    tlon    freq
OMEGA-D                  46.4    98.3    10.2
path_id                  lat1    lon1    lat2    lon2
Mediterranean            30.0    10.0    45.0   -45.0
bearng   rlat     rlon     rrho
  24.0   99.0      0.0      0.
mds    lat      lon      rho     azim     dip  bfield  sigma   epsr   beta  hprime
  4    46.4     98.3      0.     13.6    74.6  0.5[illegible]  1.E-02  15.   0.30   74.0
  4    49.8     96.0     420.    17.5    77.6  0.5[illegible]  1.E-03  15.   0.30   74.0
  4    54.6     91.9    1020.    27.2    81.2  0.588   3.E-04  10.   0.30   74.0
  4    55.5     91.0    1140.    30.0    81.8  0.588   3.E-03  15.   0.30   74.0
  4    57.1     89.3    1340.    35.7    82.8  0.587   4.E+00  81.   0.30   74.0
  4    64.8     77.7    2400.    84.3    85.0  0.570   3.E-04  10.   0.30   74.0
  4    65.6     76.0    2520.    89.9    84.9  0.567   4.E+00  81.   0.30   74.0
  4    67.2     72.2    2760.    99.5    84.6  0.560   3.E-04  10.   0.30   74.0
  4    68.6     67.9    3000.   107.0    84.1  0.554   4.E+00  81.   0.30   74.0
  4    72.1     51.6    3720.   119.5    82.6  0.534   1.E-05   5.   0.30   74.0
  4    73.7     23.7    4640.   124.9    80.6  0.515   1.E-04  10.   0.30   74.0
  4    73.6     20.5    4740.   125.3    80.4  0.513   4.E+00  81.   0.30   74.0
  4    68.7    -15.1    6100.   130.2    77.3  0.501   3.E-03  15.   0.30   74.0
  4    67.2    -19.8    6360.   131.6    76.6  0.500   1.E-03  15.   0.30   74.0
  4    65.9    -23.0    6560.   132.7    76.0  0.499   4.E+00  81.   0.30   74.0
  4    64.4    -26.1    6780.   134.0    75.4  0.498   3.E-03  15.   0.30   74.0
  4    63.0    -28.7    6980.   135.3    74.7  0.498   1.E-02  15.   0.30   74.0
  4    62.2    -30.1    7100.   136.1    74.3  0.497   3.E-03  15.   0.30   74.0
  4    61.5    -31.3    7200.   136.7    74.0  0.497   1.E-02  15.   0.30   74.0
  4    60.4    -32.8    7340.   137.7    73.5  0.497   3.E-03  15.   0.30   74.0
  4    59.4    -34.2    7480.   138.6    72.9  0.496   3.E-02  15.   0.30   74.0
  4    57.9    -36.0    7680.   140.0    72.1  0.495   1.E-02  15.   0.30   74.0
  4    54.9    -39.2    8060.   142.7    70.5  0.494   3.E-02  15.   0.30   74.0
  4    54.0    -40.1    8180.   143.5    69.9  0.493   1.E-02  15.   0.30   74.0
  4    43.8    -47.5    9440.   151.5    62.1  0.479   4.E+00  81.   0.30   74.0
  4    40.9    -49.1    9780.   153.4    59.3  0.472   1.E-02  15.   0.30   74.0
  4    40.1    -49.6    9880.   153.9    58.4  0.470   4.E+00  81.   0.30   74.0
  4    36.9    -51.1   10260.   155.7    54.8  0.461   3.E-03  15.   0.30   74.0
  4    34.9    -52.0   10500.   156.8    52.2  0.455   3.E-03  15.   0.30   74.0
       99.0
```

Figure 3: SCAN Output for MDS files

```
file_id:   11DEC89 LSF [.lwp.tst]SAMPLE.mds
           11DEC89 XKL [.lwp.tst]SAMPLE.lwf
           ***
prgm_id:   LWPM-V10
case_id:   OMEGA coverage of the Mediterranean
prfl_id:   LWPM Day
xmtr_id                 tlat     tlon    freq
OMEGA-D                 46.4     98.3    10.2
path_id                 lat1     lon1    lat2     lon2
Mediterranean           30.0     10.0    45.0    -45.0
no nrpt bearng  rhomx  rlat     rlon    rrho     pwr      dist  incl headng talt ralt
 1  551   24.0 10500.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   30.0 11000.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   33.0 11000.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   36.0 11000.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   39.0 10500.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   42.0 10500.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   45.0 10500.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   48.0 10000.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   51.0 10000.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   54.0  9500.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   57.0  9500.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   60.0  9000.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   63.0  9000.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
 1  551   72.0  8500.  99.0     0.0      0.      10.       0.    0.    0.0   0.0  0.0
```

Figure 4: SCAN Output for LWF files

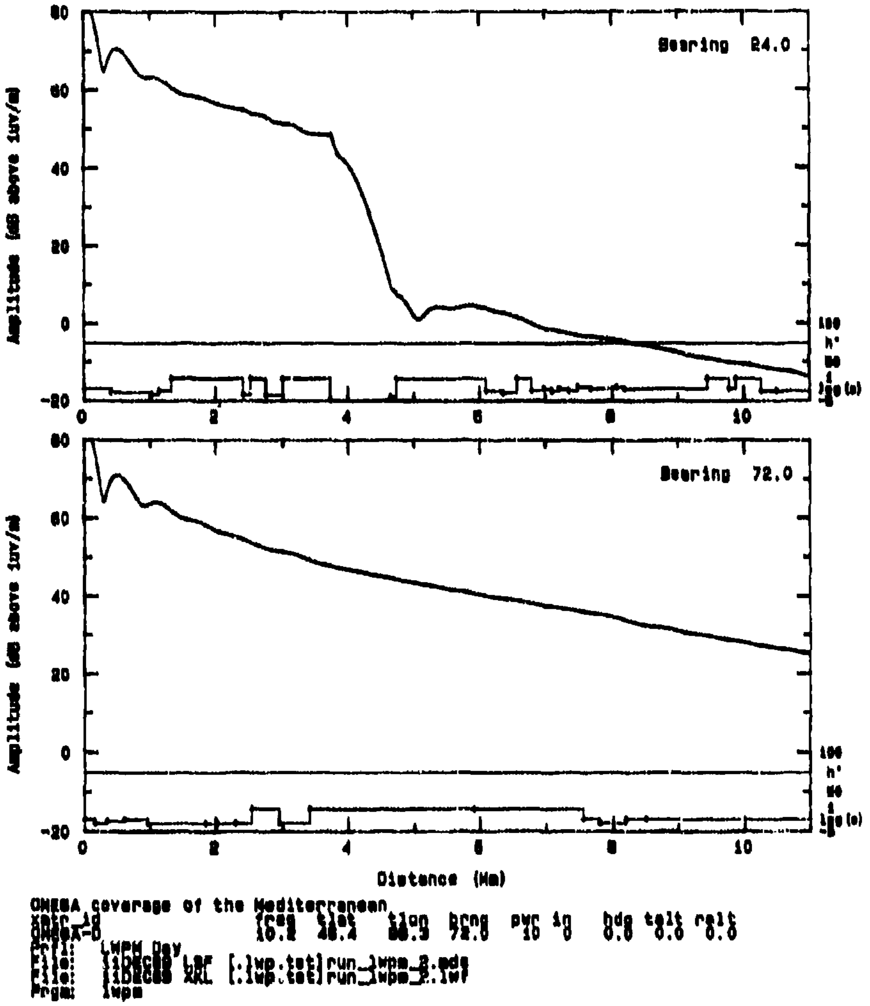

Figure 5: Output from PLOT_LWF for two paths in Figure 2.

```
file_id:  11DEC89 LSF [.lwp.tst]SAMPLE.mds
          11DEC89 XKL [.lwp.tst]SAMPLE.lwf
          11DEC89 XKL [.lwp.tst]SAMPLE_mediterranean.grd
prgm_id:  LWPM-V10
case_id:  OMEGA coverage of the Mediterranean
prfl_id:  LWPM Day
xmtr_id                 tlat     tlon    freq
OMEGA-D                 46.4     98.3    10.2
path_id                 lat1     lon1    lat2     lon2
Mediterranean           30.0     10.0    45.0     -45.0
area_id                xlat1    xlon1   xlat2    xlon2   nlat nlon
Mediterranean           30.0     10.0    45.0     -45.0    13   45
no power  incl  headng  talt   ralt  mn/dy/yr:UT    bandw  adjny  stndev
 1   10.   0.     0.0    0.0    0.0  00/00/00:0000    0.     0.0     3.0
```

Figure 6: SCAN Output for GRD files

```
$ run lwpc-dir:plot_grd
case-id     OMEGA coverage of the Mediterranean
tx          SAMPLE
op-area     Mediterranean      30 10 45 -45
map-area    Mediterranean rect 30 10 45 -45 6 3
map-type    land coast
a-noise     ntia July 18 1000
cntr-range  ,,3
ta-level    50
plt-s       1
plt-s/n     1
start
quit
```

Figure 7: Sample run stream for PLOT_GRD

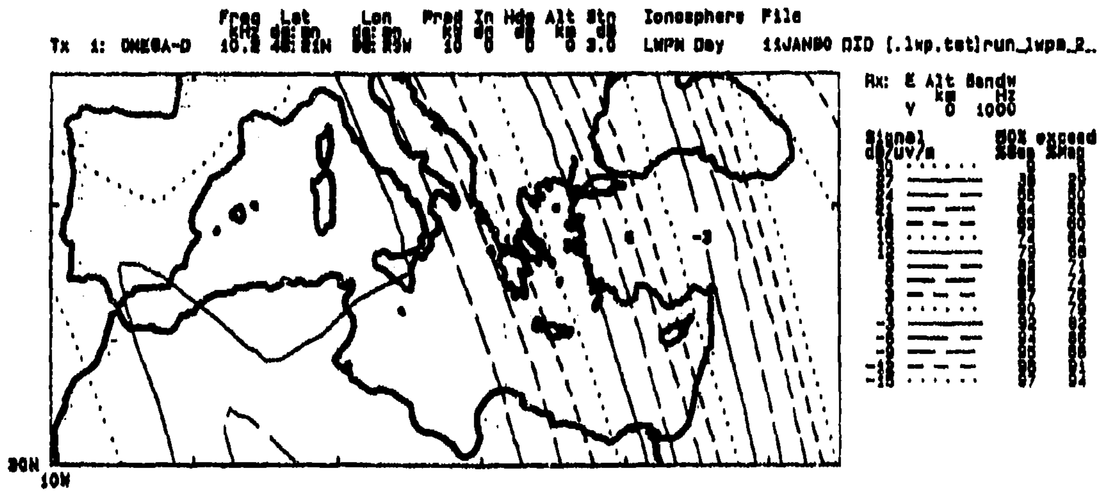

Figure 8: Signal contours for the operating area of Figure 2.

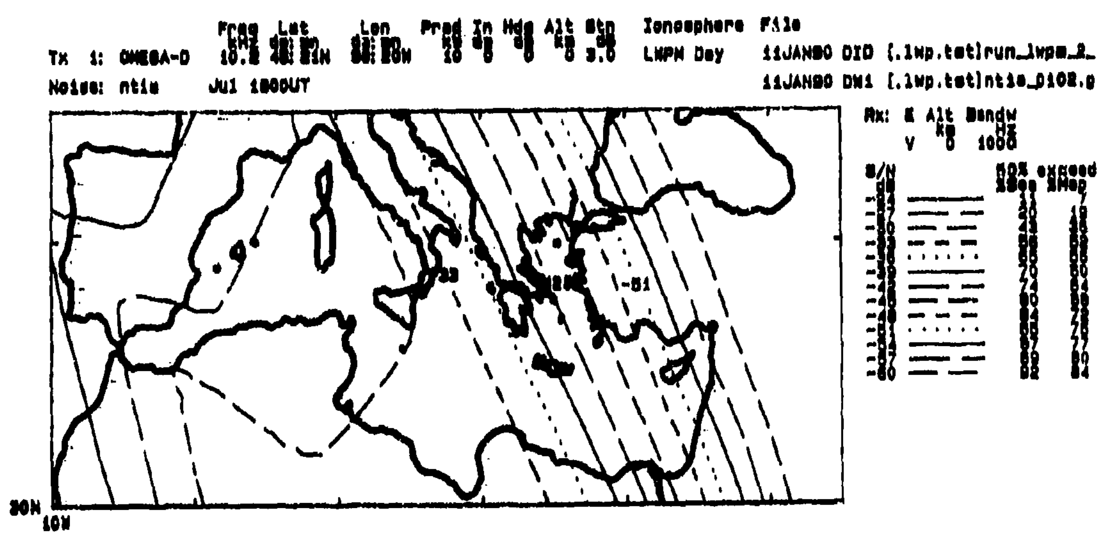

Figure 9: SNR contours for the operating area of Figure 2.