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THESIS

RADAR MODEL WITH TERRAIN EFFECTS

by

James W. Meritt

March 1982

Thesis Advisor: James K. Hartman

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This thesis presents an interactive naval radar model which computes radar detection in the presence of land masses, using a parametric terrain description.

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Radar Model with Terrain Effects

by

James W. Meritt
Lieutenant, United States Navy
B.S., University of South Carolina, 1972

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
March, 1982

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ABSTRACT

This thesis presents an interactive naval radar model which computes radar detection in the presence of land masses, using a parametric terrain description.

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I. INTRODUCTION

This thesis presents a novel naval radar model which computes radar detection in the presence of land masses. The model is an interactive computer program which accepts scenarios and radar parameters from the user and displays a map of the area indicating where targets can and cannot be detected. The resulting map can be displayed at the user's computer terminal or printed offline.

Major capabilities of the model are:

1. parametric terrain description
2. user friendly input and output
3. beach return masking
4. radar shadowing
5. side lobe masking

The program is written in FORTRAN IV H (extended), to be executed on an IBM 3033 using an IBM 3278.2 video computer terminal. A data file which contains a parametric terrain description must be prepared before using this program, but all other required input is prompted at the terminal.

II. MOTIVATION

The Warfare Environment Simulator (WES) used by Command, Communications, and Control personnel is a large scale computerized naval wargame. The land displayed by the system does not affect the radar detection probabilities. This is one of the artificialities in the game.

During Exercise BRIGHT HORIZON '81 the tactic of concealing small vessels in fjords and among islands to prevent radar detection until a surprise attack could be made was demonstrated to be effective. This technique, while it could be anticipated, can not currently be modeled in WES.

North Atlantic Treaty Organization naval warfare scenarios virtually always include the proximity of land. United States Navy scenarios are primarily open ocean. It seems necessary to incorporate NATO problems into USN procedures. With this in mind, a method of encoding terrain data was combined with a radar model to produce a method of producing maps of the area in question with the concealed areas displayed.

III. MODEL

A. WARFARE ENVIRONMENT SIMULATOR

1. Basic System

WES is a computer program that simulates a naval warfare environment in a large computer system, enabling personnel to engage in realistic wartime scenarios without the expense of actually losing ships and lives [Ref. 1].

2. Radar Equation

The WES model uses the standard radar equation modified to handle ducting and clutter effects. Equation (1) is used to calculate signal excess.

$$SE=Pt+2G+2W+TCS-4DR-B-NF-L-C \quad (1)$$

SE = signal excess, dB

Pt = peak transmitted power, dB//w

G = antenna gain, dB

W = wavelength, dB//cm

TCS= target cross section, dB//m

D = ducting factor

R = target range, dB//nm

B = receiver noise figure, dB

NF = noise factor, dB

C = clutter factor, dB

L = system loss factor, dB

System loss factor includes antenna pattern loss and atmospheric absorption loss. Antenna pattern loss takes into account the change in illuminating energy levels brought about by the lobe shape of the radar main beam pattern. The internal system losses are assigned to be 1.5 dB, a typical value for most radars. Atmospheric absorption loss is added to this. Atmospheric absorption loss is frequency dependent, and is assigned as 1 dB around 300 MHz and 3.5 dB at 5000 MHz, at target ranges typical to naval radars.

The clutter factor describes the losses due to sea clutter. It is taken to be 10log(Hw), where Hw is the significant wave height in feet.

The ducting factor is used to describe the effects of ducted propagation, especially surface evaporation ducts. An approximate fit of the IREPS model of a leaky wave guide is used.[1] A strength of zero indicates no ducting, and a radar horizon limitation is evoked. If a duct is present, this restriction is lifted. A strength of five corresponds

---

[1]Integrated Refractive Effects Prediction System, developed by Naval Ocean Systems Center and implemented on the Hewlett-Packard model 9845 desktop calculator. It is a shipboard environmental data processor and display system designed to aid in the assessment of the impact of lower atmospheric refraction effects on Naval EM systems.

to a "perfect", lossless duct with free space propagation within its boundaries. Values for D are selected from Table (1).

Table 1: Ducting Factor

strength	0	1	2	3	4	5
D	1.0	1.35	1.20	1.11	1.05	1.0

The noise factor is used to include jamming. It is not used in this model.

See subsection 3 below for the method of processing signal excess. The method used in determining the radar target cross section of ships is discussed in Chapter III, section c, subsection 3.

For this model an additional term is included. The "obstacle gain" is calculated and subtracted from the right hand side of the equation.[2]

3. Signal Excess model

Signal excess is converted to probability of detection on the basis of false alarm number and pulse integration as discussed below.

False alarm number is the number of radar signal pulses that are received before a non-signal noise pulse is

----

[2]For obstacle gain see chapter III, section c, subsection 6.

received. WES, as well as this model, offers the use of four different values.

The number of pulses illuminating the target is evaluated by use of equation (2).

$$Np = \frac{60(PRR)(BW)}{(SW)(ARR)} \tag{2}$$

where:

Np = number of pulses

PRR = pulse repetition rate, pulses per second

BW = horizontal beam width, in degrees

SW = angular width of swepth sector, in degrees

ARR = scan rate, in scans per minute

The distribution of signal excess can be closely approximated by a normal distribution with a mean defined by the number of pulses integrated, probability of false alarm, and a standard deviation of 7dB. A large table contains the mean of the signal excess distribution (mu) in terms of number of pulses integrated and probability of false alarm.

Conversion of computed signal excess (SE) to probability of detection is accomplished in WES as follows.

The signal excess is normalized by equation (3).

$$z = (se-mu)/sd \tag{3}$$

The z is used to enter a table of cumulative standardized normal values to get the probability of detection which is used in the WES simulation.

This model runs the process in reverse: given the desired probability of detection, the number of pulses, and an assumed standard deviation the standardized normal probability distribution is used to find a corresponding signal excess, which can then be compared to the realized signal excess to determine if the target will be detected within the constraints given.

4. Conditions and Assumptions

A number of constants are established in the WES model, as well as in this modified version. Many of them will be discussed in the sections in which they are singularly appropriate, but some of the more general ones will be mentioned here.

A 4/3 earth radius is used in calculating the distance to the radar horizon to compensate for standard atmospheric refraction.

Receiver noise figure is taken as a constant value of 5.5 dB, a value which is primarily thermal noise under standard conditions.

The return from land is not directly modeled. The geometrical cross section of a portion of parametrized terrain is assumed to be the radar cross section. Data is unavailable on the reflectivity of varying types of surface to compute the true radar cross section given the geometric cross section, so a reflectivity of 1 is assumed. A slope of at least .02 is required for beach return, when checking from the seaward side, and a slope of at least .3 is required for return in the sidelobes. In either case, the land must be at least as high as the target vessel. These values were determined by experimenting with the geometrical cross section of a terrain sample. The steeper slope required for the sidelobe masking is caused by the lower gain present in the sidelobe.

B. SMOLER-MILLS MODEL

1. Basic System

In 1979 Josef Smoler wrote his Master's thesis on an "Operational Lanchester-Type Model of Small Unit Land Combat" [Ref. 2]. It is a time sequenced, deterministic, battalion-level, force-on-force model implemented on a digital computer. It contained a method of modeling terrain developed by Christopher James Needles in March, 1976 for his Master's Thesis "Parameterization of Terrain in Army Combat Analysis" [Ref. 3]. In September 1980 Glenn M. Mills attempted to overcome shortfalls in the original model, and added several enrichments to provide added user flexibility [Ref. 4]. A user's manual is provided for this model on a permanent disk in the W. R. Church Computer Center. These Fortran programs conduct their Army battles over land, using Needles' terrain model and Professor Hartman's elevation and line-of-sight routines.[3] These routines were used to model the land in this naval model. Only minor modifications were required, partially tc adjust to the change in scale and partially to remove some strictly land effects.

2. Terrain Model

In 1976 Christopher James Needles presented and evaluated a methodology of parameterizing terrain for use in land combat analysis [Ref. 3]. This was a shift from the traditional method of digitizing data compiled from terrain and interpolating. He described a method by which terrain could be created mathematically by using a modified bivariate normal probability density function.

The common form of the bivariate normal density function is given by equation (4).

----

[3]See sections three and four of this chapter for ELEV and LOS.

$$f(X,Y) = \frac{1}{2\pi\sigma_x\sigma_y(1-\rho^2)} \exp\left\{ -\frac{1}{2(1-\rho^2)} \left[\left(\frac{X-\mu_x}{\sigma_x}\right)^2 - 2\rho\frac{(X-\mu_x)}{\sigma_x}\frac{(Y-\mu_y)}{\sigma_y} + \left(\frac{Y-\quad}{\quad}\right)^2 \right] \right\} \qquad (4)$$

The equation has been modified by making the normalizing constant equal the the maximum elevation of the desired terrain. The resulting equation has sufficient parameters to model many different types of "hills", and by carefully combining these hills different types of terrain can be modeled.

This method of terrain modeling is currently being used by the STAR model written in SIMSCRIPT II.5, but the Fortran version of the method has also been used, in the Smoler-Mills model previously described.*

See Figure (1) for an illustration on how the hills are constructed.

3. Elevation Routine

The purpose of the function ELEV is to compute terrain elevation for given X, Y coordinates.

The elvation routine was initially provided to Josef Smoler by Professor James K. Hartman for use in his land combat model, and subsequently by Mills in his modification of Smoler's model [Ref. 5].

The point defined by the coordinates is examined to determine if any of the "hills" are present, and if so which

----

*Simulation of Tactical Alternative Response, a ground-air combat model developed at the Naval Postgraduate School.

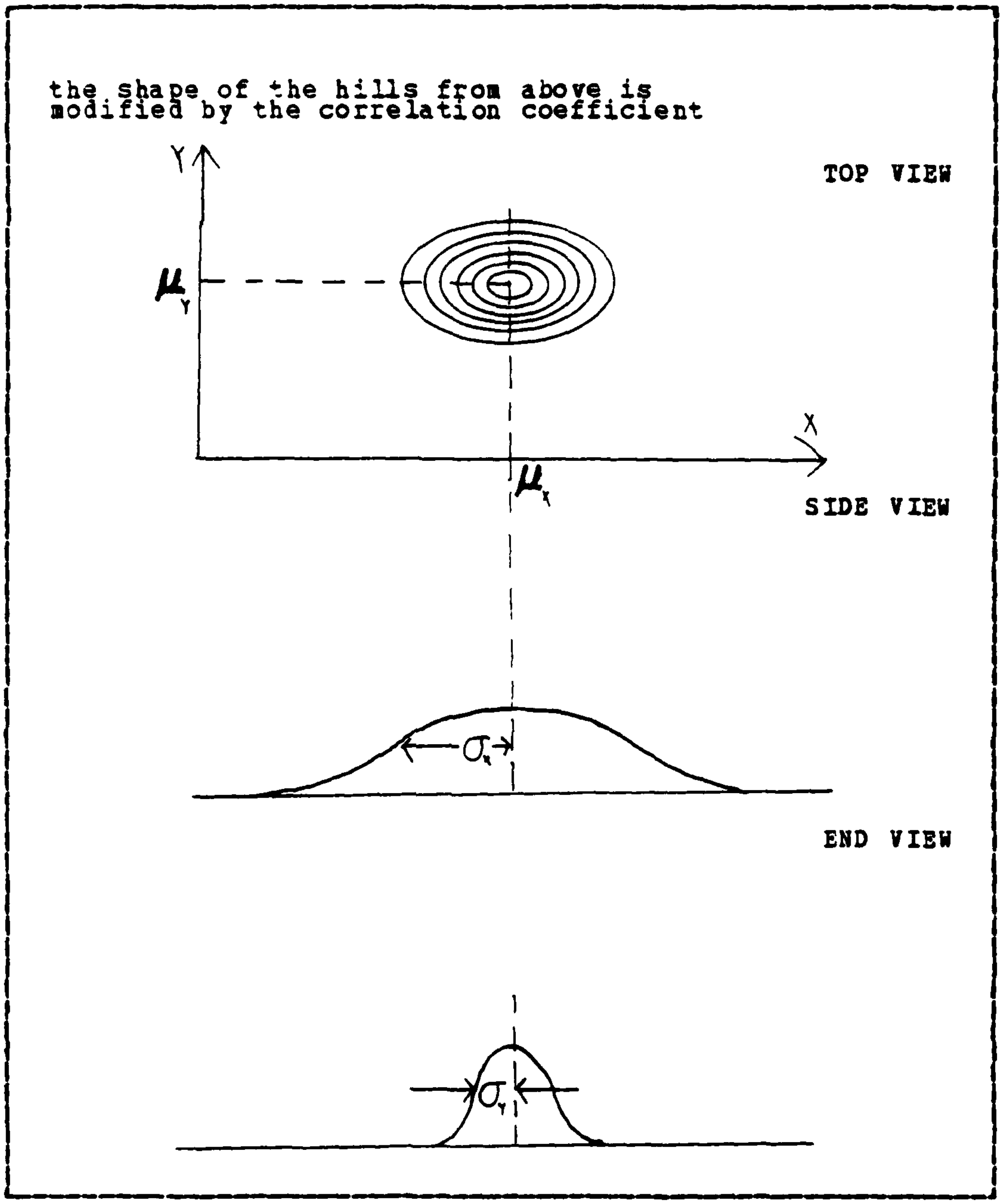

Figure 1: Terrain Structure

ones. Only those which are effective are evaluated, minimizing the computer time required for each point. Given the index of the "effective hill", the appropriate paramenters are selected and applied to the previously defined modified bivariate normal distribution to derive the terrain elevation at that point.

In a second elevation routine, ELEVG, the gradient components of the equation are computed as well as the elevation, allowing the slope to be determined easily.

The procedure to add tree height to the top of the hills to increase elevation has been removed for this radar model.

4. Line of Sight Routine

The line-of-sight routine was also developed by Professor Hartman [Ref. 5]. Its development and use follow closely those of the elevation routines.

Line of sight (LOS) is a purely geometric computation assuming perfect visibility. The result of the LOS computation was initially the percent of the vertical height of the target visable to the searcher, and the percent visible of the searcher by the target. In addition, the range and elevation of the point which causes the target to be totally obstructed is now returned.

The basic procedure is: "Find the lowest sight line from the searcher over the terrain. Extend this line to the target's position and compare its extrapolated height to the target's elevation. Thus compute the percent visible."

In as much as the searcher and the target are both ships, the searcher is assumed to be at sea level. If ducting is present, the target is also assumed to be at sea level. If ducting is not present, an additional routine computes the amounts by which both the obstructing terrain and the target are lowered by the earth's curvature.

As in ELEV, forest calculations have been removed.

C. AUGMENTATION

1. Introduction

The STAR LOS and ELEV routines have been combined with the WES radar equation to get a routine to calculate detection behind and next to land.

A separate routine was written to calculate beach effects, side lobe effects, and a special routine to provide output on an IBM 3278 computer video terminal.

After accepting preliminary terrain, radar, target, and environmental data the program samples sites a designated distance apart from a specified reference point to create a matrix containing either elevation or detection data, to be examined at the terminal, with an option to print it on a line printer.

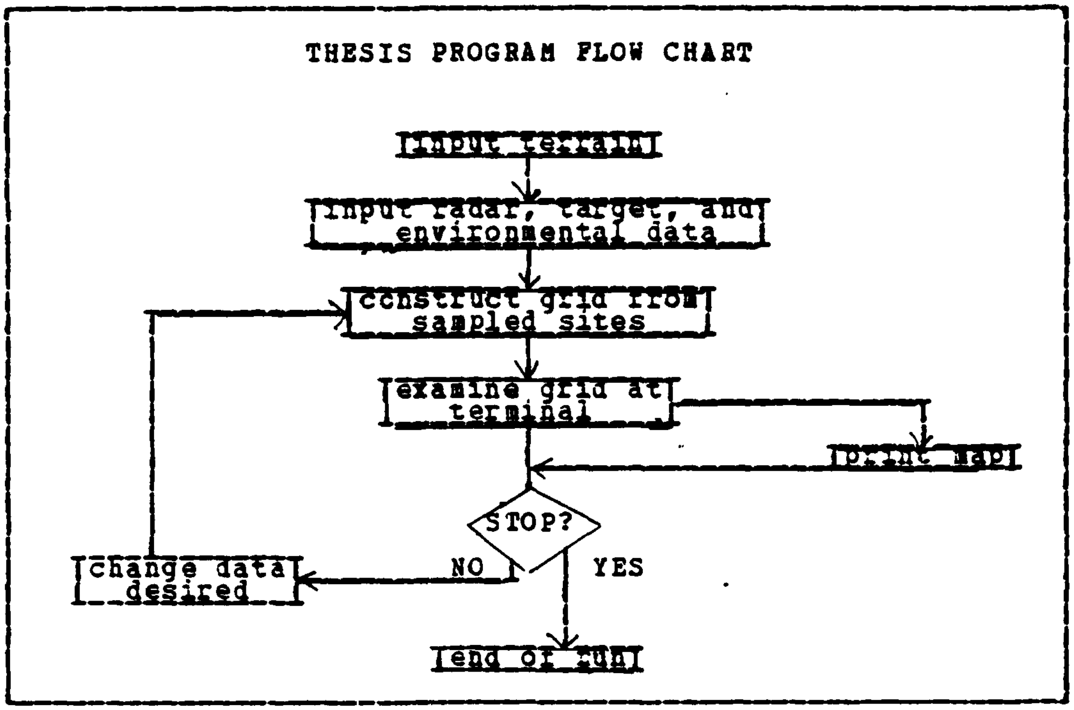

Figure 2: Flow Chart

Figure (2) presents a flow chart of the overall program.

2. <u>Input Routines</u>

The following subroutines were developed to input the information required by the programs.

a. Terrain Data

A number of different items are required to define the terrain. The elevation of the reference plane must be entered, along with the total number of "hills". For each hill, the X and Y coordinates, its maximum elevation, the standard deviation in both the X and Y direction, and the correlation between them must be entered for each hill. This defines the hill, in as much as these are the appropriate parameters in the bivariate normal distribution described in the section on the terrain model.[5]

The data for the terrain is assumed to be contained in a data file accessable by the virtual machine. Two routines adapted from ones writted by Mark L. Yount perform the necessary file definitions, after requesting filename, filetype, and filemode (filemode defaults to a) at the terminal.

Information for up to 100 hills covering over an area 200nm by 200nm may be entered this way.

b. Radar Data

Radar information may be entered in either of two ways: First, it may be stored in a data file, and loaded similiar to the method utilized to load terrain data. Second, it may be entered at the terminal, in response to questions on the screen. Table (2) lists the information required.

----

[5]For BVN equation used in the terrain model, see chapter III, section B, subsection 2.

Table 2: Required Radar Data

NAME OF RADAR SYSTEM
PEAK TRANSMITTED POWER (WATTS)
RECEIVER IF BANDWIDTH (MHZ)
PULSE REPITION RATE (PPS)
HORIZONTAL BEAM WIDTH (DEGREES)
VERTICAL BEAM WIDTH (DEGREES)
ANGULAR WIDTH OF SWEPTH SECTOR (DEGREES)
SCAN RATE (SPM)
PULSE LENGTH (MICROSECONDS)
FREQUENCY (HERTZ)
ANTENNA HEIGHT (FEET)
S-E COORDINATES OF RADAR (NM)
NUMBER OF LOBES (UP TO 5)
STRONGEST # LOBES (DEGREES CW FROM MAIN LOBE)

(note: the "#" above represents the number of lobes desired)

c. Target Data

The target data is entered in the same subroutine. Table (3) lists the required information.

Table 3: Target Data

IDENTIFIER FOR TARGET
VERTICAL SIZE OF TARGET (FEET)
TARGET MAXIMUM DISPLACEMENT (KILOTONS)

d. Other

Additional information is required for the program. It consists of environmental and probabilistic data.

Table 4: Environmental and Probabilistic Data

DUCTING STRENGTH (INTEGER-0 FOR NO DUCT TO 5 FOR PERFECT DUCT)
PROBABILITY OF FALSE ALARM
REQUIRED PROBABILITY OF DETECTION FOR SINGLE SWEEP
SIGNIFICANT WAVE HEIGHT (FEET)

Table (4) lists these additional requirements.

A copy of initial conditions is then available to be printed on the line printer upon request. Figure (3) is an example of this listing.

```
SPS-55  RADAR
=============
PEAK TRANSMITTED POWER:                              1.30E+05 WATTS
ANTENNA GAIN:                                            3.14 DB
FREQUENCY:                                           1.00E+10 HERTZ
RECEIVER NOISE FIGURE:                                   0.08 DB
HORIZONTAL BEAM WIDTH:                                   1.50 DEGREES
VERTICAL BEAM WIDTH:                                    20.00 DEGREES
SCAN RATE:                                              16.00 RPM
PULSE LENGTH:                                            1.00 MICROSECONDS
PULSE REPETITION RATE:                                 750.00 PPS
PULSES ON TGT PER SWEEP                                    11
MINIMUM RANGE:                                           0.08 NM
STRONGEST 2 LOBE(S) (DEGREES CW):                          45 315
MAXIMUM UNAMBIGIOUS RANGE:                             109.26 NM
TARGET: KANIN
===============
TARGET MAXIMUM DISPLACEMENT:                             4.60 KILOTONS
VERTICAL SIZE OF TARGET:                                52.50 FEET
TARGET RADAR CROSS-SECTION:                          5.13E+04 SQ METERS
ENVIRONMENTAL DATA:
===================
SIGNIFICANT WAVE HEIGHT:                                 3.00 FEET
DUCTING STRENGTH
0 FOR NO DUCT UP TO 5 FOR PERFECT DUCT                      5
DUE TO DUCTING, THERE IS NO RADAR HORIZON
HILL  1 IS     40.00 METERS TALL, LOCATED AT  150.00 150.00
DETECTION DATA
==============
PRCBABILITY OF FALSE ALARM                               1.E-4
PROBABILITY OF DETECTION                                 0.30
```

Figure 3: Initial Conditions

Finally, information relevant to the actual plotting is requested. Simply enter the number of nautical miles between sample points desired and a reference point on the overall map and the routine commences its calculations.

3. Computing Target Cross Section

The Target Characterization Branch of the Naval Research Laboratory has made carefully controlled measurements of the radar cross sections of a number of naval ships. A simple empirical expression has been obtained (see equation (5)) that expresses the cross section as a function of the displacement and the frequency.

$$tcs=52f^{\frac{1}{2}}d^{\frac{3}{2}} \qquad (5)$$

Where:

tcs = Target cross section is square meters

f = radar frequency in megahertz

d = displacement in kilotons (full load)

This expression provides reasonable approximations for the microwave band common to most naval radars, and over the displacement range of 2000 to 17000 tons [Ref. 6].

4. Beach Return Masking

Each segment of land (elevation greater than 0.5 meters) is checked to determine if it is a beach. This is done in subroutine BEACH by checking every adjacent sample point in the grid and determining if any of them is ocean (elevation less than 0.5 meters). If this is the case, it is assumed that a potential target can get next to it. Next subroutine BRTN estimates the geometric cross section of a section of beach. This is done by first determining the area within one resolution cell. The size of the cell is determined by taking the area between two circles at the given range separated by the range resolution and between two radial lines separated by the angular resolution. Subroutine ELEVG is then called to determine the slope of the section of beach at the point of concern as seen by the radar. The effective area of the resolution cell is determined by taking the sine of this slope and multiplying it by the resolution cell total area. See Figure (4) for an illustration.

If the effective cross section determined in the above manner is greater than that of the target vessel, it is assumed that any return from the beach would mask the return from the target.

5. Main and Side Lobe Interference

LAND is a subroutine which checks the main lobe and given major side lobes for the presence of land. A procedure similiar to BEACH is used to determine the proximity of

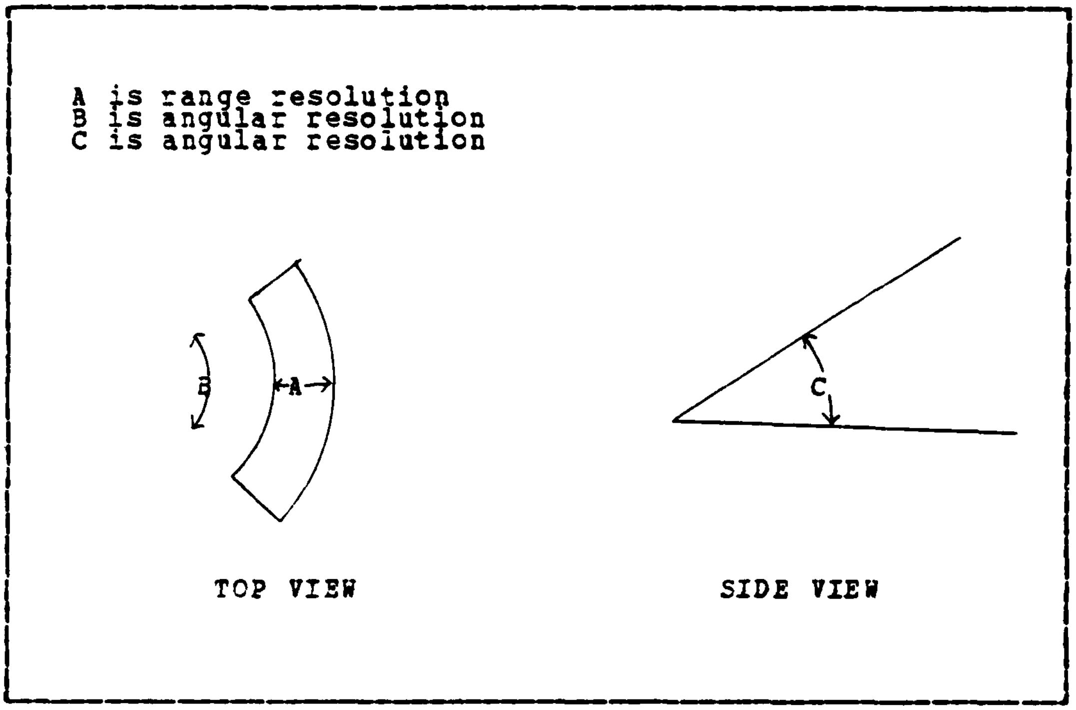

Figure 4: Geometric Area

land, and once this is established ELEVG is used to check if there is sufficient slope for radar return.

Side lobes are checked by using ELEVG to check for land at the same range as the point to be evaluated in the direction of a major lobe when the target is centered in the side lobe.

The presence of land of sufficient height and slope in any of the inspected locations indicates that masking takes place.

6. Radar Shadowing

After calling the line-of-sight routine, the program treats the contact in one of three ways:

a. Case 1

There is no obstruction. The obstruction gain is set to zero.

b. Case 2

There is only partial obstruction. The target is at the interface between shadow and illumination. The obstacle gain is set at the log of an eighth, in accordance with the basic optical interference technique. [Ref. 7]

c. Case 3

The target is totally obstructed, in which case the subroutine OBGAIN is called to determine obstacle gain.

OBGAIN calculates the "obstacle gain" created by the radio waves being diffracted over the hill tops. A "knife edge" obstacle is assumed, and the calculations are performed using Picquenard's radio wave propagation equations [Ref. 8]. If the hill is not the highest of the radar, the hill, and the target it is assumed that the target is again at the interface and the same value mentioned earlier is returned, otherwise the calculations continue.

In any case, the obstacle gain is treated as an attenuation and subtracted from the other values in the equation used to calculate signal excess.

7. Display Routine

RMAP is a version of TMAP modified to allow the use of special symbols. TMAP has been submitted for the NONIMSL LIBRARY at NPS. The routine interactively takes an array and prepares a contour map for the vicinity of a given point. The output is on a terminal or on the printer, at the option of the user, interactively taking input from the keyboard. Passed arguments: A is the array to be plotted

N and M are its dimension

SFNM is the number of nautical miles between points.

Other arguments are requested at the terminal. the program is a modified version of Professor Gilles Cantin's program CTRMAP version of OCT 1, 1969, adapted for terminal use.

Figure (5) is given on the screen immediately before commencing the plots, either initially at the terminal or printed at the top of the paper printout.

```
THERE ARE    1.00NM BETWEEN POINTS
        O=  0.0             RANGE(    0.0                            0.400000E+02 )
        A=    2.000     B=    4.000    C=    6.000     D=    8.000     E=   10.00
        F=   12.000     G=   14.000    H=   16.000     I=   18.000     J=   20.00
        Q=   22.000     R=   24.000    S=   26.000     T=   28.000     U=   30.00
        V=   32.000     W=   34.000    X=   36.000     Y=   38.000     Z=   40.00
        $=RADAR         *=MASKED
```

Figure 5: Symbology for Plot

Note: On Figure(6), the "$" representing the radar's position is off the screen.

Figure (6) is an example of what appears on the terminal. The paper listing gives the entire map area, with symbology as before.

```
PLOT CENTERED ON  45.00NM SOUTH AND  45.00NM EAST

                      *****A
                    *** BB   A
                  ***      B  A
                *** C  D  C B
               ** CD EEEE D  B A
             ***CD  F G   EDC  A
            **        I  G    BA
           **  EF IJ Q JI  E  BA
          **   E HJ SS  J  ED  A
          *   E   TU UT  IGE   A
         **  E  QSU WW USQ E   *
         **C FH SUW  W S  F CBA***
         * D J  UW   WU J  D  ******
        **C  I T   Z  T I  CB ********
        * D  J UW   WU J  D  ************
       **C F  S W  WUS HF CBA*************
       *  E  QSU WW USQ  E B ****************
      **  EGI  TU UT    E  ******************
```

Figure 6: Screen Display

In the screen display given, the points are one nautical mile apart, with the radar located approximately 20nm to the northwest of the center of the island. The letters roughly centered in the screen correspond to terrain elevation, as coded in Figure (2). The '*' on the left edge correspond to a steep beach, where the beach return is stronger than the reflection from the target. The '*' to the right define the area shadowed by the island. The clear area around it is sea level.

8. <u>Rerun with Changed Data</u>

This routine allows the model to be rerun after changing a select number of the parameters. Figure (7) is the screen display which is the menu of allowable changes. Simply enter the number corresponding to the desired change and then the new value. The routine will offer to print the new parameters and then construct another matrix containing elevation and detection data for examination.

```
                TERRAIN HELD CONSTANT

 1- NAME OF RADAR                    11- ANTENNA HEIGHT
 2- PEAK POWER                       12- RADAR COORDINATES
 3- BANDWIDTH                        13- TARGET NAME
 4- PRR                              14- TARGET SIZE
 5- HORIZONTAL BEAM WIDTH            15- TARGET DISPLACEMENT
 6- VERTICAL BEAM WIDTH              16- DUCTING STRENGTH
 7- SECTOR SIZE                      17- PROBABILITY OF FALSE ALARM
 8- SCAN RATE                        18- PROBABILITY OF DETECTION
 9- PULSE LENGTH                     19- WAVE HEIGHT
10- FREQUENCY                        20- END OF CHANGES
```

Figure 7: Menu Selection

IV. FUTURE

A. POSSIBLE UTILIZATION OF MODEL

This model has applications in planning and training for Naval Operations.

For training purposes, this model could be incorporated into WES or other sea combat models to better reflect detection in areas where land is present. For such uses, the input and display routines could be trimmed, and only the point in question would be analyzed, not an entire map array.

For planning purposes, ship courses could be selected to provide maximum radar protection from land shadowing, or the inverse, to allow minimum terrain interference for stationing radar guard ships, could be found after parameterizing the applicable areas.

B. FUTURE ENHANCEMENTS

Parabolic cylinders could be utilized to model the refraction effects instead of knife-edges to improve the model somewhat [Ref. 9].

The input and output routines could be modified to take better advantage of facilities available (plotting terminals, for instance).

A method to find the beach, instead of identifying if a particular point is within a given distance of the sea, would enable better coastal coverage.

Radar return is often observed behind obstacles under conditions in which simple knife-edge refraction cannot be responsible. The causes for these effects should be found and incorporated into the model.

For use in other models, different subroutines may be adapted for the particular model being constructed. Some subroutines will have to be entirely rewritten, especially those involving beach return which use mapped data already calculated, to handle single-point problems.

APPENDIX A

PROGRAM LISTING

The following is an entire listing of the radar model. It has been specially written to be run on the IBM 3033 on a IBM 3278.2 video terminal, the facilities available at the Naval Postgraduate School. Appendix B contains and explanation of each of the subroutines.

```
      COMMON /IPRT/ IPRT
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /CCUNTR/KH, KHW, KV, KN, KGRS, KELL, KINT
      COMMON /GRID/ LST(10,10),NHL(10,10),LISTH(450),KHREP(100),KTREP
      COMMON /RADAR/PT,G,W,B,RNF,RL,C,D,RMIN,RMAX,ARES,RRES,LOBE,
     +ALOBE(5)
      DIMENSION IGX(100),IGY(100),IEL(100),CS1(100),CS2(100),EA(350,350)
      IPRT=1
      CALL INTRO
      WRITE (6,20)
20    FORMAT (' TERRAIN DATA REQUIRED:')
      CALL SETUP
      CALL INPUT (DSE,TCS,ISTR,HR,SIZEA,SIZEB,RX,RY,TMICA)
500   CONTINUE
      CALL PRTCMS ('CLRSCRN')
15    WRITE (6,1)
1     FORMAT (' INPUT NUMBER OF NM DESIRED BETWEEN SAMPLE POINTS')
      READ (5,*) SFNM
      WRITE (6,120)
120   FORMAT (' ENTER COORDINATES FOR REFERENCE POINTS')
      READ (5,*) XREFNM,YREFNM
      XREF=XREFNM*1829.27
      YREF=YREFNM*1829.27
      NEA=INT(AMIN1(350./SFNM,350.))
      SF=SFNM*1829.27
      DO 5 I=1,NEA
      DO 10 J=1,NEA
      X=(SF*FLOAT(I))+XREF
      Y=(SF*FLOAT(J))+YREF
      CALL ELEV(X,Y,TMAC)
      EA(I,J)=TMAC
10    CONTINUE
5     CONTINUE
       DO 100 J=1,NEA
       DO 101 K=1,NEA
C     CHECK IF WITHIN RANGE
       X=(SF*FLOAT(J))+XREF
       Y=(SF*FLOAT(K))+YREF
       CALL RANGE (RX,RY,X,Y,FAR)
       IF (EA(J,K).LT.0.5.AND.FAR.GT.RMAX) GOTO 50
C     CHECK IF INSIDE MINIMUM RANGE
      IF (EA(J,K).LT.0.5.AND.FAR.LT.RMIN) GOTO 50
C     CHECK IF IT IS A BEACH, AND IF THE TERRAIN IS ELEVATED AT LEAST
C     AS HIGH AS THE TARGET SHIP IS, CHECK FOR RETURN
      KOAST=0
      IF (EA(J,K).GT.SIZEB) CALL BEACH (J,K,EA,NEA,NEA,KOAST)
```

```
      ECS=0.
      IF (KOAST.EQ.1) CALL BRTN (RX,RY,X,Y,ECS)
      IF (ECS.GE.TCS) GOTO 50
C     EVERYTHING AFTER HERE IS AN OCEAN-LEVEL CHECK ONLY
      IF (EA(J,K).GT.0.5) GOTO 101
C     CHECK IF LAND IS IN MAIN OR SIDE LOBES
      CALL LAND (RX,RY,X,Y,FAR,SIZEB,EA,350,350,J,K,XREF,YREF,SF,MASK)
      IF (MASK.EQ.1) GOTO 50
C     CHECK IF TOTALLY OBSTRUCTED
      TMACB=0.
      VISFRB=1.
      CALL LOS (RX,RY,0.,TMICA,SIZEA,X,Y,TMACB,0.,SIZEB,1,0,
     +VISFRA,VISFRB,HW,WRANGE,ISTR)
C     TREAT THE CONTACT IN ONE OF THREE CASES
C         1-THERE IS NO OBSTRUCTION
      IF (VISFRB.EQ.1.) OBGN=0.
      IF (VISFRB.EQ.1.) GOTO 49
C         2-THE TARGET IS AT THE INTERFACE
C     FROM "FUNDAMENTALS OF OPTICS" BY JENKINS AND WHITE, SECOND EDITION
C     PAGE 366..'INTENSITY AT THE EDGE OF THE SHADOW IS 1/4 OF THAT FOR
C     THE UNOBSTRUCTED WAVE'. I TAKE THE 2-WAY TRIP AND LOG FORM FOR THE
C     DESIRED VALUE.
      IF (0..LT.VISFRB.AND.VISFRB.LT.1.) OBGN=.90309
      IF (VISFRB.GT.0.) GOTO 49
C         3-THE TARGET IS COMPLETELY SHADOWED
      CALL OBGAIN (FAR,HW,WRANGE,TMICA,SIZEB,OBGN)
C     CALCULATE SIGNAL EXCESS
49    CALL GETSE (FAR,TCS,SE,OBGN)
C     SEE IF RETURNED SIGNAL IS STRONG ENOUGH
      IF (SE.LT.DSE) GOTO 50
      GOTO 101
50    EA(J,K)=-2.0
101   CONTINUE
100   CONTINUE
C     PUT THE SHIP SYMBOL "$" AS CLOSE AS POSSIBLE TO ITS LOCATION
      KX=INT((RX-XREF)/SF)
      IF (KX.LT.1) KX=1
      IF (KX.GT.350) KX=350
      KY=INT((RY-YREF)/SF)
      IF (KY.LT.1) KY=1
      IF (KY.GT.350) KY=350
      EA(KX,KY)=-4.0
      CALL RMAP (EA,NEA,NEA,SFNM)
      WRITE (6,501)
501   FORMAT (' DO YOU WANT TO RERUN WITH DIFFERENT DATA?')
      CALL ANSWER (K)
      IF (K.EQ.0) GOTO 502
      CALL MOD (DSE,TCS,ISTR,HR,SIZEA,SIZED,RX,RY,TMICA)
```

```
      GOTO 500
502   CONTINUE
      STOP
      END
      SUBROUTINE ANSWER (K)
      REAL*8 ANS, Y/'YES'/,N/'NO '/
1     WRITE (6,2)
2     FORMAT (' ENTER YES OR NO')
      READ (5,3) ANS
3     FORMAT (1A3)
      IF (ANS.NE.Y) GOTO 4
      K=1
      RETURN
4     IF (ANS.NE.N) GOTO 5
      K=0
      RETURN
5     WRITE (6,6)
6     FORMAT (' ENTRY NOT RECOGNIZED')
      GOTO 1
      END
      SUBROUTINE BEACH (IX,IY,A,N,M,KOAST)
      DIMENSION A(N,M)
C     ROUTINE DETERMINES IF POINT OF LAND (POSITION IX,IY IN A)
C     IS ADJACENT TO THE SEA. KOAST IS RETURNED
C     IF KOAST=0   THE POINT IS INLAND
C     IF KOAST=1   THE POINT IS ADJACENT TO THE SEA
      KOAST=0
      IXT=MAX(1,IX-1)
      IXB=MIN(M,IX+1)
      IYL=MAX(IY-1,1)
      IYR=MIN(N,IY+1)
      ALERT=1.0
      DO 5 I=IXT,IXB
      DO 10 J=IYL,IYR
10    ALERT=ALERT*A(I,J)
5     CONTINUE
      IF (ALERT.EQ.0.) KOAST=1
      RETURN
      END
      SUBROUTINE BRTN (X1,Y1,X2,Y2,ECS)
      COMMON /RADAR/PT,G,W,B,RNF,RL,C,D,RMIN,RMAX,ARES,RRES,LOBE,
     +ALOBE(5)
C     ROUTINE CALCULATES EFFECTIVE RADAR CROSS SECTION OF AN AREA OF
C     LAND THE SIZE OF A RESOLUTION CELL WHICH MIGHT CONTAIN A TARGET
C     X1,Y1 ARE THE POSITION OF THE RADAR
C     X2,Y2 ARE THE POSITION OF THE BEACH
C     RRES IS THE RADAR RANGE RESOLUTION
C     ARES IS THE RADAR ANGULAR RESOLUTION
```

```
C     THMAC IS THE BEACH ELEVATION
C     ECS IS THE RETURNED CROSS SECTION
      ECS=0.0
      DX=X2-X1
      DY=Y2-Y1
      RANGE=SQRT(DX**2+DY**2)
      CALL ELEVG(X2,Y2,THMAC,GX,GY)
      TILT=(DX*GX+DY*GY)/RANGE
      IF (TILT.LE.0.0) RETURN
      PCT=SIN(TILT)
      ECS=.023271057*RANGE*RRES*ARES*PCT
      RETURN
      END
      SUBROUTINE ECURVE (RANGE,DROP)
C     SUBROUTINE COMPUTES THE ELEVATION REDUCTION CAUSED BY EARTH'S
C     CURVATURE PRESENT AT GIVEN RANGE.
C     EER IS THE EFFECTIVE EARTH RADIUS IN METERS
C     RANGE IS THE DISTANCE TRAVELED ALONG THE EARTH
C     DROP IS THE LOSS IN ELEVATION RESULTING FROM THE EARTH'S CURVATURE
      DATA EER/16951757./
      DROP=EER-EER*SIN(1.5707963-(RANGE/EER))
      RETURN
      END
      SUBROUTINE ELEV(X,Y,THMAC)
C
      COMMON /IPRT/ IPRT
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /GRID/ LST(10,10),NHL(10,10),LISTH(450),KHREP(100),KTREP
      DATA NGRID/10/,GSIZE/54878./
      IF(IPRT.GE.20) WRITE(6,388)
388   FORMAT(' ************************ENTERED SUBROUTINE ELEV*******')
C FUNCTION TO COMPUTE TERRAIN ELEVATION FOR GIVEN X, Y COORDINATES.
C     THMAC IS THE RETURNED ELEVATION
      ZMAX=BASE
      IX=1+IFIX(X/GSIZE)
      IF(IX.GT.NGRID)  IX=NGRID
      IY=1+IFIX(Y/GSIZE)
      IF(IY.GT.NGRID)  IY=NGRID
      IF(NHL(IX,IY).EQ.0) GO TO 150
      LS=LST(IX,IY)
      LEND=LS+NHL(IX,IY)-1
      DO 100 L=LS,LEND
      I=LISTH(L)
      QX=(X-XC(I))/SX(I)
      QXSQ=QX*QX
      IF (QXSQ .GE.9.) GO TO 100
```

```
      QY=(Y-YC(I))/SY(I)
      QYSQ=QY*QY
      IF (QYSQ .GE. 9.) GO TO 100
      QXY=TWORHO(I)*QX*QY
      FACTOR=SCALE(I)*(QXSQ+QYSQ+QXY)
      IF(FACTOR.LT.-3.) GO TO 100
      HT=PEAK(I)*EXP(FACTOR)
      IF(HT.LE.ZMAX) GO TO 100
      ZMAX=HT
  100 CONTINUE
  150 TMAC=ZMAX
      IF(IPRT.GE.20) WRITE(6,389) X,Y,TMAC
389   FORMAT(' LEAVE SUBRTN ELEV: X = ',F8.0,' Y = ',F8.0, 'TMAC = ',
     2      F12.6)
      RETURN
      END
      SUBROUTINE ELEVG(X,Y,TMAC,GX,GY)
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /GRID/ LST(10,10),NHL(10,10),LISTH(450),KHREP(100),KTREP
      DATA NGRID/10/,GSIZE/54878./
C FUNCTION TO COMPUTE TERRAIN ELEVATION (TMAC) FOR GIVEN X, Y
C COORDINATES AND GRADIENT COMPONENTS GX AND GY.
      ZMAX=BASE
      GX=0.
      GY=0.
      IX=1+IFIX(X/GSIZE)
      IF(IX.GT.NGRID)   IX=NGRID
      IY=1+IFIX(Y/GSIZE)
      IF(IY.GT.NGRID)   IY=NGRID
      IF(NHL(IX,IY).EQ.0) GO TO 150
      LS=LST(IX,IY)
      LEND=LS+NHL(IX,IY)-1
      DO 100 L=LS,LEND
      I=LISTH(L)
      QX=(X-XC(I))/SX(I)
      QXSQ=QX*QX
      IF (QXSQ .GE.9.) GO TO 100
      QY=(Y-YC(I))/SY(I)
      QYSQ=QY*QY
      IF (QYSQ .GE. 9.) GO TO 100
      QXY=TWORHO(I)*QX*QY
      SC=SCALE(I)
      FACTOR=SC*(QXSQ+QYSQ+QXY)
      IF(FACTOR.LT.-3.) GO TO 100
      HT=PEAK(I)*EXP(FACTOR)
      IF(HT.LE.ZMAX) GO TO 100
```

```
      ZMAX = HT
      GX=HT*SC*(2.0*QX+QY)/SX(I)
      GY=HT*SC*(2.0*QY+QX)/SY(I)
100   CONTINUE
150   THAC=ZMAX
      RETURN
      END
      SUBROUTINE GETSE (R,TCS,SE,OBGN)
C     ROUTINE PROCESSES RADAR DATA TO COMPUTE SIGNAL EXCESS RETURNED
C     TO RADAR FROM CONTACT UNDER SPECIFIED CONDITIONS
      COMMON /RADAR/PT,G,W,B,RNF,RL,C,D,RMIN,RMAX,ARES,RRES,LOBE,
     +ALOBE(5)
      TCSMOD=ALOG10(TCS)
      RMOD=ALOG10(R/1829.27)
      SE=PT+2.*G+2.*W+TCSMOD-4.*D*RMOD-B-RNF-RL-C-OBGN
      RETURN
      END
      SUBROUTINE INPUT (SE,TCS,ISTR,HR,SIZEA,SIZEB,RX,RY,THICA)
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /RADAR/PT,G,W,B,RNF,RL,C,D,RMIN,RMAX,ARES,RRES,LOBE,
     +ALOBE(5)
      COMMON /RDR/RDR$,TGT$,PRR,BW,BV,FREQ,SW,ARR,PL,DISP,HT,HW,PDET,PTR
      COMMON /HILL/ XMC(100),YMC(100)
      REAL*8 RDR$,TGT$,IPP$(4)/'E-4','E-6','E-8','E-10'/
      DIMENSION ALOBES(5)
C     ROUTINE READS IN THE RADAR, TARGET, ENVIRONMENTAL, AND DETECTION
C     DATA, EITHER FROM THE TERMINAL OR FROM A DATA FILE.
      IPRT=0
      L=5
C     EQUATIONS TO DETERMINE SECONDARY RADAR CHARISTICS FROM INPUT DATA
C     TAKEN FROM "HOW TO SPEAK RADAR" BY ARNOLD E. AIKER, VARIAN
C     ASSOCIATES REVISED JANUARY 1974
      CALL PRTCMS ('CLRSCRN')
      WRITE (6,300)
300   FORMAT (' DOES A FILE EXIST WHICH HAS THE RADAR,TARGET,DETECTION',
     +', AND ENVIRONMENTAL DATA?')
      CALL ANSWER (ITF)
      IF (ITF.EQ.1) L=7
      IF (ITF.EQ.1) CALL SELECT
      CALL PRTCMS ('CLRSCRN')
      IF (ITF.EQ.1) WRITE (6,350)
350   FORMAT (' THE FOLLOWING INFORMATION IS BEING ENTERED:')
      IF (ITF.EQ.0) WRITE (6,351)
351   FORMAT (' ENTER THE FOLLOWING DATA:')
      WRITE (6,22)
22    FORMAT (' NAME OF RADAR SYSTEM')
```

```
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,23) RDR$
23    FORMAT (1A7)
      WRITE (6,1)
1     FORMAT (' PEAK TRANSMITTED POWER (WATTS)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) PTR
      PT=10.*ALOG10(PTR)
      WRITE (6,3)
3     FORMAT (' RECEIVER IF BANDWIDTH (MHZ)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) B
      B=ALOG10(B)
      WRITE (6,4)
4     FORMAT (' PULSE REPETITION RATE (PPS)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) PRR
      WRITE (6,5)
5     FORMAT (' HORIZONTAL BEAM WIDTH (DEGREES)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) BW
      WRITE (6,20)
20    FORMAT (' VERTICAL BEAM WIDTH (DEGREES)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) BV
C     ARES IS ANGULAR RESOLUTION
      ARES=BW
C     G IS ANTENNA GAIN
      G=ALOG10(41252.962/(BW*BV))
      WRITE (6,6)
6     FORMAT (' ANGULAR WIDTH OF SWEPTH SECTOR (DEGREES)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) SW
      IF (ITF.EQ.0) CALL FRTCMS ('CLRSCRN')
      WRITE (6,7)
7     FORMAT (' SCAN RATE (SPM)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) ARR
      WRITE (6,8)
8     FORMAT (' PULSE LENGTH (MICROSECONDS)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) PL
      WRITE (6,9)
9     FORMAT (' FREQUENCY (HERTZ)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) FREQ
      SIZEA=299792500./(BV*FREQ)
      WRITE (6,10)
```

```
10      FORMAT (' ANTENNA HEIGHT (FEET)')
        IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
        READ (L,*) HR
C       TMICA IS THE HEIGHT OF THE ANTENNA (IN METERS) FOR LOS
        TMICA=.3048781*HR
        WRITE (6,90)
90      FORMAT (' NUMBER OF SIDE LOBES (UP TO 5)')
        IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
        READ (L,*) LOBE
        IF (LOBE.GT.5) LOBE=5
        IF (LOBE.LT.1) GOTO 95
        WRITE (6,91) LOBE
91      FORMAT (' STRONGEST ',I3,' LOBES (DEGREES CW)')
        IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
        READ (L,*) (ALOBES(I),I=1,LOBE)
        DO 92 I=1,LOBE
92      ALOBE(I)=ALOBES(I)/57.295779
95      CONTINUE
        WRITE (6,70)
70      FORMAT (' S-E COORDINATES OF RADAR (NM)')
        IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
        READ (L,*) RX,RY
        RX=RX*1829.27
        RY=RY*1829.27
C       W IS WAVELENGTH (DB//CM)
        W=ALOG10(29979250000./FREQ)
C       NP IS NUMBER OF PULSES ILLUMINATING A TARGET PER SWEEP
        NP=INT((60.*PRR*BW)/(SW*ARR))
        IF (ITF.EQ.0) CALL FRTCMS ('CLRSCRN')
        WRITE (6,24)
24      FORMAT (' IDENTIFIER FOR TARGET')
        IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
        READ (L,23) TGT$
        WRITE (6,19)
19      FORMAT (' VERTICAL SIZE OF TARGET (FEET)')
        IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
        READ (L,*) HT
C       SIZEB IS VERTICAL SIZE OF THE TARGET (IN METERS) FOR LOS
        SIZEB = HT*.3048781
        WRITE (6,11)
11      FORMAT (' TARGET MAXIMUM DISPLACEMENT (KILOTONS)')
        IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
        READ (L,*) DISP
        IF ((DISP.LT.2.).OR.(DISP.GT.17.)) WRITE (6,12)
12      FORMAT (' WARNING: TARGET CROSS SECTION MAY BE IN ERROR')
C       AN EMPIRICAL FORMULA FOR THE RADAR CROSS SECTION OF SHIPS AT
C       GRAZING INCIDENCE.....IEEE MAR 74
        TCS=52.*SQRT(FREQ/1.E6)*DISP**1.5
```

```
      IF (ITF.EQ.0) CALL FRTCMS ('CLRSCRN')
13    WRITE (6,14)
14    FORMAT (' DUCTING STRENGTH (INTEGER-0 FOR NO DUCT UP TO 5 FOR',
     +' PERFECT DUCT)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) ISTR
      IF ((ISTR.LT.0).OR.(ISTR.GT.5)) GOTO 13
C     APPROXIMATE FIT OF IREPS MODEL, AS USED IN W.E.S.
C     IF ISTR IS GREATER THAN 0, THE HORIZON CONSTRAINT IS REMOVED
      IF (ISTR.EQ.0) D=1.
      IF (ISTR.EQ.1) D=1.35
      IF (ISTR.EQ.2) D=1.2
      IF (ISTR.EQ.3) D=1.11
      IF (ISTR.EQ.4) D=1.05
      IF (ISTR.EQ.5) D=1.0
      IF (((FREQ.LT.19.E7).OR.(FREQ.GT.12.E9)).AND.(ISTR.GT.0))
     + WRITE (6,15)
15    FORMAT (' WARNING: DUCTING MAY BE IN ERROR')
      IF (ITF.EQ.1) CALL FRTCMS ('CLRSCRN')
      WRITE (6,16)
16    FORMAT (' PROBABILITY OF FALSE ALARM:'/' 1=E-4'/' 2=E-6'/
     +' 3=E-8'/' 4=E-10')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) IPF
200   WRITE (6,21)
21    FORMAT (' REQUIRED PROBABILITY OF DETECTION FOR SINGLE SWEEP')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) PDET
      IF (PDET.LT.1.0) GOTO 82
      WRITE (6,81)
81    FORMAT (' PROBABILITY MUST BE EXPRESSED AS A VALUE LESS THAN 1')
      GOTO 200
82    CONTINUE
      CALL PD2SE (SE,NP,IPF,PDET)
C     SE IS THE SIGNAL EXCESS REQUIRED TO GIVE THE DESIRED PDET
      WRITE (6,17)
17    FORMAT (' SIGNIFICANT WAVE HEIGHT (FEET)')
      IF (ITF.EQ.1) CALL FRTCMS ('CP','SL','1','SEC')
      READ (L,*) HW
C     C IS CLUTTER FACTOR (DB)
      C=10.*ALOG10(HW)
C**DEFAULT VALUES ARE TAKEN TO BE THE SAME AS THOSE USED IN THE
C**WARFARE ENVIRONMENT SIMULATOR PREPARED BY THE NAVAL OCEAN SYSTEMS
C**CENTER IN SAN DIEGO. FOR REVISION SEE MR. BRANDENBURG, AUTOVON
C*933-2083
C     RL IS SYSTEM LOSS FACTOR (INCLUDES ANTENNA PATTERN (ASSUMED AS
C     1.5DB) AND ATMOSPHERIC ABSORPTION LOSS (1DB AT 300MHZ AND
C     3.5DB AT 5000MHZ OVER NAVAL OPERATIONAL RADAR RANGES))
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```
      IF (FREQ.LT.2.65E9) RL=2.5
      IF (FREQ.GE.2.65E9) RL=5.0
C     RNF IS RECEIVER NOISE FIGURE (DB), MOSTLY THERMAL NOISE.
      RNF=5.5
      RMIN=PL*149.896250
C     RRES IS RANGE RESOLUTION
      RRES=RMIN
      RMAX=149896250./PRR
      IF (ISTR.EQ.0) RHNM=1.25*(SQRT(HR)+SQRT(HT))
      RHORIZ=RHNM*1829.27
      CALL PRTCMS ('CLRSCRN')
      WRITE (6,30)
      L=5
30    FORMAT (/////////' DO YOU WANT A PRINTED COPY OF RADAR, TARGET, ',
     +'DETECTION AND ENVIRONMENT DATA?')
      CALL ANSWER (KP)
      IF (KP.EQ.0) GOTO 100
      CALL PRTCMS ('FILEDEF','08','PRINT','(','RECFM','FA','BLOCK',
     +'133')
      WRITE (8,31) RDR$
31    FORMAT (' ',1A7,' RADAR'/' =============')
      WRITE (8,32) PTR
32    FORMAT (' PEAK TRANSMITTED POWER:',T50,1PE10.2,' WATTS')
      WRITE (8,33) G
33    FORMAT (' ANTENNA GAIN:',T50,F10.2)
      WRITE (8,34) FREQ
34    FORMAT (' FREQUENCY:',T50,1PE10.2,' HERTZ')
      WRITE (8,35) B
35    FORMAT (' RECEIVER NOISE FIGURE:',T50,F10.2,' DB')
      WRITE (8,36) BW
36    FORMAT (' HORIZONTAL BEAM WIDTH:',T50,F10.2,' DEGREES')
      WRITE (8,37) BV
37    FORMAT (' VERTICAL BEAM WIDTH:',T50,F10.2,' DEGREES')
      WRITE (8,38) ARR
38    FORMAT (' SCAN RATE:',T50,F10.2,' RPM')
      WRITE (8,39) PL
39    FORMAT (' PULSE LENGTH:',T50,F10.2,' MICROSECONDS')
      WRITE (8,47) PRR
47    FORMAT (' PULSE REPETITION RATE:',T50,F10.2,' PPS')
      WRITE (8,40) NP
40    FORMAT (' PULSES ON TGT PER SWEEP:',T50,I10)
      RMINI=RMIN/1829.27
      WRITE (8,45) RMINI
45    FORMAT (' MINIMUM RANGE:',T50,F10.2,' NM')
      WRITE (8,123) LOBE, (ALOBES(I),I=1,LOBE)
123   FORMAT (' STRONGEST ',I3,' LOBE(S) (DEGREES CW):',T50,5F10.2)
      RMA=RMAX/1829.27
      WRITE (8,46) RMA
```

```
46    FORMAT (' MAXIMUM UNAMBIGIOUS RANGE:',T50,F10.2,' NM')
      WRITE (8,41) TGT$
41    FORMAT ('0TARGET:' 1A7/' ===============')
      WRITE (8,42) DISP
42    FORMAT (' TARGET MAXIMUM DISPLACEMENT:',T50,F10.2,' KILOTONS')
      WRITE (8,43) HT
43    FORMAT (' VERTICAL SIZE OF TARGET:'T50,F10.2,' FEET')
      WRITE (8,44) TCS
44    FORMAT (' TARGET RADAR CROSS-SECTION:',T50,1PE10.2,' SQ METERS')
      IF ((DISP.LT.2.).OR.(DISP.GT.17.)) WRITE (8,12)
      WRITE (8,50)
50    FORMAT ('0ENVIRONMENTAL DATA:'/' ===================')
      WRITE (8,51) HW
51    FORMAT (' SIGNIFICANT WAVE HEIGHT:',T50,F10.2,' FEET')
      WRITE (8,52) ISTR
52    FORMAT (' DUCTING STRENGTH'/' 0 FOR NO DUCT UP TO 5 FOR ',
     +'PERFECT DUCT',T50,I10)
      IF (((FREQ.LT.19.E7).OR.(FREQ.GT.12.E9)).AND.(ISTR.GT.0))
     +WRITE (8,15)
      IF (ISTR.EQ.0) WRITE (8,53) RHNM
53    FORMAT (' RADAR HORIZON:',T50,F10.2,' NM')
      IF (ISTR.GT.0) WRITE (8,54)
54    FORMAT (' DUE TO DUCTING, THERE IS NO RADAR HORIZON')
      DO 80 I=1,NHILLS
      WRITE (8,63) I,PEAK(I),XMC(I),YMC(I)
80    CONTINUE
      WRITE (8,60)
60    FORMAT ('0DETECTION DATA'/' ==============')
      WRITE (8,61) IPF$(IPF)
61    FORMAT (' PROBABILITY OF FALSE ALARM?: ',T50,'     1.',1A3)
      WRITE (8,62) PDET
62    FORMAT (' PROBABILITY OF DETECTION: ',T50,F10.2)
63    FORMAT (' HILL ',I2,' IS ',F10.2,' METERS TALL, LOCATED AT ',
     +2(1X,F6.2))
100   IF (ISTR.EQ.0) RMAX=AMIN1(RMAX,RHORIZ)
      CALL PRTCMS ('FILEDEF','05','TERM')
      RETURN
      END
      SUBROUTINE INTRO
      CALL PRTCMS ('CLRSCRN')
      WRITE (6,1)
1     FORMAT (//////' ',T20,'THESIS PROJECT FOR JAMES W. MERITT ',
     +/'0',T20,'RADAR MODEL WITH TERRAIN EFFECTS'
     +,/' ',T20,'================================'
     +/' ',T17,'THESIS FOR MASTERS OF OPERATIONS RESEARCH'/
     +'0',T20,'THESIS ADVISOR PROFESSOR HARTMAN'/
     +' ',T20,'SECOND READER PROFESSOR FORREST')
      CALL PRTCMS ('CP','SL','5','SEC')
```

```
      CALL PRTCMS ('CLRSCRN')
      RETURN
      END
      SUBROUTINE KOVER(ZO,TMACT,SIZET,ZT,S,HTS,ZS,VISFRT)
      COMMON /IPRT/ IPRT
C
      IF(IPRT.GE.10) WRITE(6,388)
388   FORMAT(' ************************ENTERED SUBROUTINE KOVER*******')
      IF(S.EQ.0.) GO TO 2000
      IF(HTS.GE.ZS) GO TO 2050
      HEXT=ZO+(HTS-ZO)/S
      EVIST=AMAX1(HEXT,TMACT)
      IF(EVIST.GE.ZT) GO TO 2050
      IF(EVIST.LE.ZT-SIZET) RETURN
      VIS=(ZT-EVIST)/SIZET
      IF(VIS.LT.VISFRT) VISFRT=VIS
      RETURN
2000  IF(HTS.LT.ZO) RETURN
2050  VISFRT=0.0
      IF(IPRT.GE.10) WRITE(6,389)
389   FORMAT(' ************************LEAVING SUBROUTINE KOVER*******')
      RETURN
      END
      SUBROUTINE LAND(RX,RY,X,Y,FAR,SIZEB,A,N,M,IX,IY,XREF,YREF,SF,MASK)
      DIMENSION A(N,M)
C     SUBROUTINE DETERMINES IF LAND IS IN EITHER THE MAIN OR SIDE LOBES
C     TO DETERMINE IF MASKING WOULD TAKE PLACE.
C     NEW VARIABLE: MASK=0 IF NO MASKING TAKES PLACE
C                   MASK=1 IF MASKING TAKES PLACE
      COMMON /IPRT/ IPRT
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /COUNTR/KH, KHW, KV, KN, KGRS, KELL, KINT
      COMMON /GRID/ LST(10,10),NHL(10,10),LISTH(450),KHREP(100),KTREP
      COMMON /RADAR/FT,G,W,B,RNF,RL,C,D,RMIN,RMAX,ARES,RRES,LOBE,
     +ALOBE(5)
      DATA PI/3.14159265/,TWOPI/6.283185326/,BIG/57.289952/,S/.017455/
      MASK=0
C     CHECK IF LAND IS ADJACENT TO SEABORNE TARGET
C     PROCEDURE IS SIMILIAR TO THAT USED IN BEACH
      DX=X-RX
      DY=RY-Y
      IXT=MAX(1,IX-1)
      IXB=MIN(M,IX+1)
      IYL=MAX(IY-1,1)
      IYR=MIN(N,IY+1)
      DO 25 I=IXT,IXB
```

```
      DO 20 J=IYL,IYR
      IF (A(I,J).LT.SIZEB) GOTO 20
      SX1=(SF*FLOAT(I))+XREF
      SY1=(SF*FLOAT(J))+YREF
      CALL ELEVG(SX1,SY1,HI,GX,GY)
      TILT=(DX*GX+DY*GY)/FAR
      IF (TILT.GT.0.02) MASK=1
20    CONTINUE
25    CONTINUE
      IF (MASK.EQ.1) RETURN
C     GET BEARING TO SUSPECT POINT FROM RADAR
C     NEXT 4 STEPS ARE TO PREVENT DIVIDE ERROR
      IF ((ABS(DX).LE..01).AND.(RY.GE.Y)) TANG=1.5707963
      IF ((ABS(DX).LE..01).AND.(RY.GE.Y)) GOTO 100
      IF ((ABS(DX).LE..01).AND.(RY.LE.Y)) TANG=4.7123895
      IF ((ABS(DX).LE..01).AND.(RY.LE.Y)) GOTO 100
C     NEXT 9 STEPS ARE TO PREVENT COTAN ERROR
      RATIO = DY/DX
      IF ((-S.LT.RATIO.AND.RATIO.LT.S).AND.(DX.GT.0)) TANG=0.
      IF ((-S.LT.RATIO.AND.RATIO.LT.S).AND.(DX.GT.0)) GOTO 100
      IF ((-S.LT.RATIO.AND.RATIO.LT.S).AND.(DX.LT.0)) TANG=PI
      IF ((-S.LT.RATIO.AND.RATIO.LT.S).AND.(DX.LT.0)) GOTO 100
      IF ((RATIO.LT.-BIG.OR.RATIO.GT.BIG).AND.(DY.GT.0.)) TANG=PI/2.
      IF ((RATIO.LT.-BIG.OR.RATIO.GT.BIG).AND.(DY.GT.0.)) GOTO 100
      IF ((RATIO.LT.-BIG.OR.RATIO.GT.BIG).AND.(DY.LT.0.)) TANG=3.*PI/2.
      IF ((RATIO.LT.-BIG.OR.RATIO.GT.BIG).AND.(DY.LT.0.)) GOTO 100
C     TANG=COTAN(RATIO)
      TANG=ATAN(RATIO)
      IF (DX.LT.0.) TANG=TANG+PI
      IF ((DX.GT.0.).AND.(DY.LT.0.)) TANG=TANG+TWOPI
      IF (TANG.GT.TWOPI) TANG=TANG-TWOPI
      IF (TANG.LT.0.) TANG=TANG+TWOPI
100   CONTINUE
C     NOW CHECK FOR SIDE LOBE INTERFERENCE
      IF (LOBE.LT.1) GOTO 10
      DO 5 I=1,LOBE
         WAY=TANG+ALOBE(I)
         IF (WAY.LT.0.) WAY=WAY+TWOPI
         IF (WAY.GT.TWOPI) WAY=WAY-TWOPI
         SX1=RX+FAR*(COS(WAY))
         SY1=RY-FAR*(SIN(WAY))
         CALL ELEVG (SX1,SY1,HI,GX,GY)
         TILT=(DX*GX-DY*GY)/FAR
         IF ((HI.GT.SIZEB).AND.(TILT.GT.0.3)) MASK=1
5     CONTINUE
10    CONTINUE
      RETURN
      END
```

```
      SUBROUTINE LOS(XA,YA,TMACA,TMICA,SIZEA,XB,YB,TMACB,TMICB,SIZEB,
     -LATOB,LBTOA,VISFRA,VISFRB,HHW,WRANGE,ISTR)
C*********************************************************************
C**      THIS ROUTINE CALCULATES THE LINE-OF-SIGHT IN TERMS OF A     **
C**      FRACTION VISIBLE FOR OBSERVER TARGET PAIRS.                 **
C*********************************************************************
C       XA,YA (XB,YB)  X AND Y COORDINATES ON THE FIELD FOR A AND B
C       TMACA(TMACB)  TERRAIN ELEVATION FOR A AND B; ZERO FOR SHIPS.
C       TMICA(TMICB)  HEIGHT OF ANTENNA FOR A, 0 FOR B
C       SIZEA(SIZEB)  VERTICAL DIMENSION OF ANTENNA FOR B, VERTICAL
C                     SIZE OF THE SHIP FOR B
C       LATOB(LBTOA)  INDICATOR VARIABLE FOR LOS CALLS
C          LATOB=1    COMPUTE LOS FROM A TO B YIELDING VISFRB
C          LATOB=0    DO NOT COMPUTE A TO B
C       HHW IS THE HEIGHT OF THE OBSTRUCTING HILL
C       WRANGE IS THE RANGE FROM THE RADAR TO THE OBSTRUCTING HILL
C       VISFRA(VISFRB) FRACTION OF SIZEA(SIZEB) WHICH CAN BE SEEN BY B(A)
C       ISTR          DUCT INDICATOR. ISTR=0 NO DUCT
C                                     ISTR=1,2,3,4,5 INPROVING DUCT
      COMMON /IPRT/ IPRT
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /COUNTR/KH, KHW, KV, KN, KGRS, KELL, KINT
      COMMON /GRID/ LST(10,10),NHL(10,10),LISTH(450),KHREP(100),KTREP
      DIMENSION IGX(100),IGY(100),IEL(100),CS1(100),CS2(100)
      DATA NGRID/10/,GSIZE/54878./
      CALL RANGE (XA,YA,XB,YB,HOWFAR)
      IF (ISTR.EQ.0) CALL ECURVE (HOWFAR,TMACM)
      IF (ISTR.EQ.0) TMACB=TMACB-TMACM
      IF(IPRT.GE.20) WRITE(6,388) XA,YA,XB,YB
388   FORMAT(' ENTER SUBRTN LOS: FROM',2(2X,F8.0),' TO',2(2X,F8.0))
      VISFRA=1.
      VISFRB=1.
      XBA=XB-XA
      YBA=YB-YA
      IF((XBA.EQ.0.).AND.(YBA.EQ.0.).AND.(IPRT.GE.20)) WRITE(6,387)
387   FORMAT(' LEAVE SUBRTN LOS: POSITIONS AT SAME COORDINATES')
      IF((XBA.EQ.0.).AND.(YBA.EQ.0.)) RETURN
      IF(SIZEA+TMICA.LE.0.) GO TO 510
      IF(SIZEB+TMICB.LE.0.) GO TO 510
      IF(TMICA.LT.0.) VISFRA=1.0+TMICA/SIZEA
      IF(TMICB.LT.0.) VISFRB=1.0+TMICB/SIZEB
      ZA=TMACA + TMICA + SIZEA
      ZB=TMACB + TMICB + SIZEB
      KTREP=KTREP+1
      ZBA=ZB-ZA
      XBASQ=XBA*XBA
```

```
      YBASQ=YBA*YBA
      XYBA=XBA*YBA
      TWOXBA=2.*XBA
      TWOYBA=2.*YBA
C COMPUTE GRID SQUARES CROSSED BY A TO B LINE
      NGRSQ=0
      IF(XBA) 110,95,100
95    XBA=0.1
100   ISGX=-1
      XINC=GSIZE/XBA
      GO TO 120
110   ISGX=1
      XINC=-GSIZE/XBA
120   IF(YBA)  140,125,130
125   YBA=0.1
130   ISGY=-1
      YINC=GSIZE/YBA
      GO TO 150
140   ISGY=1
      YINC=-GSIZE/YBA
150   IX=1+IFIX(XB/GSIZE)
      IF(IX.GT.NGRID) IX=NGRID
      IY=1+IFIX(YB/GSIZE)
      IF(IY.GT.NGRID) IY=NGRID
      XNEXT=GSIZE*(FLOAT(IX)+0.5*(ISGX-1.))
      YNEXT=GSIZE*(FLOAT(IY)+0.5*(ISGY-1.))
      XSTEP=(XB-XNEXT)/XBA
      YSTEP=(YB-YNEXT)/YBA
160   NGRSQ=NGRSQ+1
      IGX(NGRSQ)=IX
      IGY(NGRSQ)=IY
      IF((XSTEP.GT.1.).AND.(YSTEP.GT.1.)) GO TO 200
      IF(XSTEP-YSTEP) 170,180,190
170   IX=IX +ISGX
      XSTEP=XSTEP+XINC
      GO TO 160
180   IX=IX+ISGX
      XSTEP=XSTEP+XINC
190   IY=IY+ISGY
      YSTEP=YSTEP+YINC
      GO TO 160
200   KGRS=KGRS+NGRSQ
C GRID SQUARE LIST NOW COMPLETE IN IGX, IGY WITH NGRSQ ENTRIES
C NOW START ON THE HILLS
  270 DO 600 K=1,NGRSQ
      IX=IGX(K)
      IY=IGY(K)
      IF(NHL(IX,IY).EQ.0) GO TO 600
```

```
      LS=LST(IX,IY)
      LEND=LS+NHL(IX,IY) -1
      DO 500 L=LS,LEND
      I=LISTH(L)
      IF(KHREP(I).EQ.KTREF) GO TO 500
      KHREP(I)=KTREP
C  PROCESSING FOR HILL I STARTS HERE
      KH=KH+1
C COMPUTE W =TOP OF THIS HILL ALONG O-T LINE
      CX=XBA/SX(I)
      CY=YBA/SY(I)
      DX=(XA-XC(I))/SX(I)
      DY=(YA-YC(I))/SY(I)
      FQ=TWOSCL(I)*(CX*DX+CY*DY+RHO(I)*(CX*DY+CY*DX))
      GQ=SCALE(I)*(CX*CX+CY*CY+TWORHO(I)*CX*CY)
      IF(GQ .EQ.0.)  GO TO 500
      W=-FQ/(2.*GQ)
      WRANGE=W*HOWFAR
      IF(ABS(W).GT.5.) GO TO 500
      FSQ=FQ*FQ
      EQ=SCALE(I)*(DX*DX+DY*DY+TWORHO(I)*DX*DY)
      POWER=EQ-FSQ/(4.*GQ)
      IF(POWER .LT. -3.) GO TO 500
      HHW=PEAK(I)*EXP(POWER)
      DROP=0.
      IF (ISTR.EQ.0.) CALL ECURVE(WRANGE,DROP)
      HHW=HHW-DROP
      KHW=KHW+1
      IF(HHW.LE.BASE.AND.TMACB.EQ.0.) GO TO 500
      ZW=ZA+W*ZBA
      IF((W.LT.0.).OR.(W.GT.1.)) GO TO 300
      IF(HHW .GE. ZW) GO TO 510
300   IF(HHW+CHTMAX.LT.AMIN1(ZA-SIZEA,ZB-SIZEB)) GO TO 500
C IF WE GET TO HERE THEN NEED TO FIND LOWEST SIGHT LINE OVER HILL
C NEWTON ITERATION A TO B GIVING VISFRB
      IF(LATOB.EQ.0) GO TO 400
      KV=KV+1
      V=W
      HHV=HHW
      NCT=0
      FV=FQ*V
      TWOGV=2.*GQ*V
330   FCNV=ZA+HHV*(TWOGV*V+FV-1.)
      KN=KN+1
      FACTOR=(TWOGV*TWOGV+2.*(GQ+TWOGV*FQ)+FSQ)
      DFCNV=HHV*V*FACTOR
      IF(ABS(DFCNV) .LT.1.E-10) GO TO 350
      V=V-FCNV/DFCNV
```

```
      FV=FQ*V
      TWOGV=2.*GQ*V
      POWER = EQ+FV+GQ*V*V
      IF(POWER .LT. -3.) GO TO 400
      HHV=PEAK(I)*EXP(POWER)
      DROP=0.
      IF (ISTR.EQ.0.) CALL ECURVE (WRANGE,DROP)
      HHV=HHV-DROP
      DHHV=HHV*(FQ+TWOGV)
      ELV=ZA+DHHV*V
      IF (ABS(HHV-ELV) .LT.1.) GO TO 350
      NCT=NCT+1
      IF (NCT.LT.10) GO TO 330
350   IF((V.LT.0.).OR.(V.GT.1.)) GO TO 400
      HTV=HHV
      ZV=ZA+V*ZBA
      CALL KOVER(ZA,TMACB,SIZEB,ZB,V,HTV,ZV,VISFRB)
      IF (VISFRB.LE.0.) GO TO 510
C NEWTON ITERATION B TO A GIVING VISFRA
      IF(ABS(V).GT.5.)GO TO 400
400   IF(LBTOA.EQ.0) GO TO 500
      KV=KV+1
      V=W
      VM1=V-1.
      HHV=HHW
      NCT=0
      FV=FQ*V
      TWOGV=2.*GQ*V
430   FCNV=ZB+HHV*((FQ+TWOGV)*VM1-1.)
      KN=KN+1
      FACTOR=(TWOGV*TWOGV+2.*(GQ+TWOGV*FQ)+FSQ)
      DFCNV=HHV*VM1*FACTOR
      IF(ABS(DFCNV) .LT.1.E-10) GO TO 450
      V=V-FCNV/DFCNV
      IF(ABS(V).GT.5.)GO TO 500
      VM1=V-1.
      FV=FQ*V
      TWOGV=2.*GQ*V
      POWER = EQ+FV+GQ*V*V
      IF(POWER .LT. -3.) GO TO 500
      HHV=PEAK(I)*EXP(POWER)
      DROP=0.
      IF (ISTR.EQ.0.) CALL ECURVE(WRANGE,DROP)
      HHV=HHV-DROP
      DHHV=HHV*(FQ+TWOGV)
      ELV=ZB+DHHV*VM1
      IF (ABS(HHV-ELV) .LT.1.) GO TO 450
      NCT=NCT+1
```

```
      IF (NCT.LT.10) GO TO 430
450   IF((V.LT.0.).OR.(V.GT.1.)) GO TO 500
      HTV=HHV
      ZV=ZA+V*ZBA
      S=-VM1
      CALL KOVER(ZB,TMACA,SIZEA,ZA,S,HTV,ZV,VISFRA)
      IF (VISFRA.LE.0.) GO TO 510
500   CONTINUE
600   CONTINUE
      IF(IPRT.GE.20) WRITE(6,386)VISFRA,VISFRB
386   FORMAT(' LEAVE SUBRTN LOS: VISFRA = ',F10.8,' VISFRB = ',F10.8)
      RETURN
510   VISFRA=0.
      VISFRB=0.
      IF(IPRT.GE.10) WRITE(6,389)
389   FORMAT(' LEAVE SUBRTN LOS: NO LINE OF SIGHT EXISTS ')
      RETURN
      END
      SUBROUTINE MOD (SE,TCS,ISTR,HR,SIZEA,SIZEB,RX,RY,TMICA)
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /RADAR/PT,G,W,B,RNF,RL,C,D,RMIN,RMAX,ARES,RRES,LOBE,
     +ALOBE(5)
      COMMON /RDR/RDR$,TGT$,PRR,BW,BV,FREQ,SW,ARR,PL,DISP,HT,HW,PDET,PTR
      COMMON /HILL/ XMC(100),YMC(100)
      REAL*8 RDR$,TGT$,IPF$(4)/'E-4','E-6','E-8','E-10'/
C     ROUTINE IS USED TO MODIFY THE RADAR, TARGET, ENVIRONMENT, AND
C     DETECTION DATA EARLIER INPUT VIA THE INPUT ROUTINE TO ALLOW
C     RE-RUNNING THE PROGRAM WITH VARING PARAMETERS.
C     FOR AN EXPLAINATION OF THE VARIABLES, SEE SUBROUTINE INPUT
1     CALL PRTCMS ('CLRSCRN')
      WRITE (6,5)
5     FORMAT ( '                        TERRAIN HELD CONSTANT'//
     +'  1- NAME OF RADAR',T40,'11- ANTENNA HEIGHT'/
     +'  2- PEAK POWER ',T40,'12- RADAR COORDINATES'/
     +'  3- BANDWIDTH',T40,'13- TARGET NAME'/
     +'  4- PRR',T40,'14- TARGET SIZE'/
     +'  5- HORIZONTAL BEAM WIDTH',T40,'15- TARGET DISPLACEMENT'/
     +'  6- VERTICAL BEAM WIDTH',T40,'16- DUCTING STRENGTH'/
     +'  7- SECTOR SIZE',T40 ,'17- PROBABILITY OF FAILURE'/
     +'  8- SCAN RATE',T40,'18- PROBABILITY OF DETECTION'/
     +'  9- PULSE LENGTH',T40,'19- WAVE HEIGHT'/
     +' 10- FREQUENCY',T40,'20- END OF CHANGES'/
     +/' ENTER NUMBER CORRESPONDING TO DESIRED CHANGE:')
      READ (5,*) K
      CALL PRTCMS ('CLRSCRN')
      GOTO (101,102,103,104,105,106,107,108,109,110,111,112,
```

```
     +113,114,115,116,117,118,119,120),K
101   WRITE (6,201)
201   FORMAT (' NAME OF RADAR SYSTEM')
      READ (5,301) RDR$
301   FORMAT (1A7)
      GOTO 1
102   WRITE (6,202)
202   FORMAT (' PEAK TRANSMITTED POWER (WATTS)')
      READ (5,*) PTR
      PT=10.*ALOG10(PTR)
      GOTO 1
103   WRITE (203)
203   FORMAT (' RECEIVER IF BANDWIDTH (MHZ)')
      READ (5,*) B
      B=ALOG10(B)
      GOTO 1
104   WRITE (6,204)
204   FORMAT (' PULSE REPETITION RATE (PPS)')
      READ (5,*) PRR
      RMAX=149896250./PRR
      GOTO 1
105   WRITE (205)
205   FORMAT (' HORIZONTAL BEAM WIDTH (DEGREES)')
      READ (5,*) BW
      ARES=BW
      GOTO 1
106   WRITE (6,206)
206   FORMAT (' VERTICAL BEAM WIDTH (DEGREES)')
      READ (5,*) BV
      GOTO 1
107   WRITE (6,207)
207   FORMAT (' ANGULAR WIDTH OF SWEPTH SECTOR (DEGREES)')
      READ (5,*) SW
      GOTO 1
108   WRITE (6,208)
208   FORMAT (' SCAN RATE (SPM)')
      READ (5,*) ARR
      GOTO 1
109   WRITE (6,209)
209   FORMAT (' PULSE LENGTH (MICROSECONDS)')
      READ (5,*) PL
      RMIN=149.89625*PL
      RRES=RMIN
      GOTO 1
110   WRITE (6,210)
210   FORMAT (' FREQUENCY (HERTZ)')
      READ (5,*) FREQ
      W=ALOG10(29979250000./FREQ)
```

```
      IF (FREQ.LT.2.65E9) RL=2.5
      IF (FREQ.GE.2.65E9) RL=5.0
      GOTO 1
111   WRITE (6,211)
211   FORMAT (' ANTENNA HEIGHT (FEET)')
      READ (5,*) HR
      THICA=.3048781*HR
      GOTO 1
112   WRITE (6,212)
212   FORMAT (' S-E COORDINATES OF RADAR (NM)')
      READ (5,*) RX,RY
      RX=RX*1829.27
      RY=RY*1829.27
      GOTO 1
113   WRITE (6,213)
213   FORMAT (' TARGET NAME')
      READ (5,301) TGT$
      GOTO 1
114   WRITE (6,214)
214   FORMAT (' SIZE OF TARGET (FEET)')
      READ (5,*) HT
      SIZEB=HT*.3048781
      GOTO 1
115   WRITE (6,215)
215   FORMAT (' TARGET MAXIMUM DISPLACEMENT (KILOTONS)')
      READ (5,*) DISP
      IF ((DISP.LT.2.).OR.(DISP.GT.17.)) WRITE (6,315)
315   FORMAT (' WARNING: TARGET CROSS SECTION MAY BE IN ERROR')
      GOTO 1
116   WRITE (6,216)
216   FORMAT (' DUCTING STRENGTH: 0 TO 5')
      READ (5,*) ISTR
      IF ((ISTR.LT.0).OR.(ISTR.GT.5)) GOTO 116
      IF (ISTR.GT.0) RMAX=149896250./PRR
      IF (ISTR.EQ.0) D=1.0
      IF (ISTR.EQ.1) D=1.35
      IF (ISTR.EQ.2) D=1.2
      IF (ISTR.EQ.3) D=1.11
      IF (ISTR.EQ.4) D=1.05
      IF (ISTR.EQ.5) D=1.0
      GOTO 1
117   WRITE (6,217)
217   FORMAT (' PROBABILITY OF FAILURE:'/' 1=E-4'/' 2=E-6'/' 3=E-8'/
     +' 4=E-10')
      READ (5,*) IPF
      GOTO 1
118   WRITE (6,218)
218   FORMAT (' SINGLE SWEEP PROBABILITY OF DETECTION')
```

```
      READ (5,*) PDET
      IF ((PDET.GT.0.).AND.(PDET.LT.1.)) GOTO 1
      WRITE (6,318)
318   FORMAT (' PROBABILITIES ARE BETWEEN ZERO AND ONE. REENTER.')
      GOTO 118
119   WRITE (6,219)
219   FORMAT (' SIGNIFICANT WAVE HEIGHT (FEET)')
      READ (5,*) HW
      C=10.*ALOG10(HW)
      GOTO 1
120   CONTINUE
      G=ALOG10(41252.962/(BW*BV))
      SIZEA=299792500/(BV*FREQ)
      NP=INT((60.*PRR*BW)/(SW*ARR))
      TCS=52.*SQRT(FREQ/1.E6)*DISP**1.5
      CALL PD2SE(SE,NP,IPF,PDET)
      IF (ISTR.EQ.0) RHNM=1.25*(SQRT(HR)+SQRT(HT))
      RHORIZ=1829.27*RHNM
      WRITE (6,30)
30    FORMAT (/////////' DO YOU WANT A PRINTED COPY OF RADAR, TARGET, ',
     +'DETECTION AND ENVIRONMENT DATA?')
      CALL ANSWER (KP)
      IF (KP.EQ.0) GOTO 100
      CALL FRTCMS ('FILEDEF','08','PRINT','(','RECFM','FA','BLOCK',
     +'133')
      WRITE (8,1000)
1000  FORMAT ('1PROJECT BEING RUN WITH REVISED DATA'
     +/' ==================================')
      WRITE (8,31) RDRS
31    FORMAT (' ',1A7,' RADAR'/' =============')
      WRITE (8,32) PTR
32    FORMAT (' PEAK TRANSMITTED POWER:',T50,1PE10.2,' WATTS')
      WRITE (8,33) G
33    FORMAT (' ANTENNA GAIN:',T50,F10.2)
      WRITE (8,34) FREQ
34    FORMAT (' FREQUENCY:',T50,1PE10.2,' HERTZ')
      WRITE (8,35) B
35    FORMAT (' RECEIVER NOISE FIGURE:',T50,F10.2,' DB')
      WRITE (8,36) BW
36    FORMAT (' HORIZONTAL BEAM WIDTH:',T50,F10.2,' DEGREES')
      WRITE (8,37) BV
37    FORMAT (' VERTICAL BEAM WIDTH:',T50,F10.2,' DEGREES')
      WRITE (8,38) ARR
38    FORMAT (' SCAN RATE:',T50,F10.2,' RPM')
      WRITE (8,39) PL
39    FORMAT (' PULSE LENGTH:',T50,F10.2,' MICROSECONDS')
      WRITE (8,47) PRR
47    FORMAT (' PULSE REPETITION RATE:',T50,F10.2,' PPS')
```

```
      WRITE (8,40) NP
40    FORMAT (' PULSES ON TGT PER SWEEP',T50,I10)
      RMINI=RMIN/1829.27
      WRITE (8,45) RMINI
45    FORMAT (' MINIMUM RANGE:',T50,F10.2,' NM')
      RMA=RMAX/1829.27
      WRITE (8,46) RMA
46    FORMAT (' MAXIMUM UNAMBIGIOUS RANGE:',T50,F10.2,' NM')
      WRITE (8,41) TGT$
41    FORMAT ('0TARGET:' 1A7/' ===============')
      WRITE (8,42) DISP
42    FORMAT (' TARGET MAXIMUM DISPLACEMENT:',T50,F10.2,' KILOTONS')
      WRITE (8,43) HT
43    FORMAT (' VERTICAL SIZE OF TARGET:'T50,F10.2,' FEET')
      WRITE (8,44) TCS
44    FORMAT (' TARGET RADAR CROSS-SECTION:',T50,1PE10.2,' SQ METERS')
      IF ((DISP.LT.2.).OR.(DISP.GT.17.)) WRITE (8,315)
      WRITE (8,50)
50    FORMAT ('0ENVIRONMENTAL DATA:'/' ===================')
      WRITE (8,51) HW
51    FORMAT (' SIGNIFICANT WAVE HEIGHT:',T50,F10.2,' FEET')
      WRITE (8,52) ISTR
52    FORMAT (' DUCTING STRENGTH'/' 0 FOR NO DUCT UP TO 5 FOR ',
     +'PERFECT DUCT',T50,I10)
      IF (((FREQ.LT.19.E7).OR.(FREQ.GT.12.E9)).AND.(ISTR.GT.0))
     +WRITE (8,15)
15    FORMAT (' WARNING: DUCTING MAY BE IN ERROR')
      IF (ISTR.EQ.0) WRITE (8,53) RHNM
53    FORMAT (' RADAR HORIZON:',T50,F10.2,' NM')
      IF (ISTR.GT.0) WRITE (8,54)
54    FORMAT (' DUE TO DUCTING, THERE IS NO RADAR HORIZON')
      DO 80 I=1,NHILLS
      WRITE (8,63) I,PEAK(I),XMC(I),YMC(I)
80    CONTINUE
      WRITE (8,60)
60    FORMAT ('0DETECTION DATA'/' ==============')
      WRITE (8,61) IPF$(IPF)
61    FORMAT (' PROBABILITY OF FAILURE ',T50,'      1.',1A3)
      WRITE (8,62) PDET
62    FORMAT (' PROBABILITY OF DETECTION ',T50,F10.2)
63    FORMAT (' HILL ',I2,' IS ',F10.2,' METERS TALL, LOCATED AT ',
     +2(1X,F6.2))
100   IF (ISTR.EQ.0) RMAX=AMIN1(RMAX,RHORIZ)
      CALL PRTCMS ('FILEDEF','05','TERM')
      RETURN
      END
      SUBROUTINE OBGAIN (FAR,HW,WRANGE,TMICA,SIZEB,OBGN)
      COMMON /RADAR/FT,G,W,B,RNP,RL,C,D,RMIN,RMAX,ARES,RRES,LOBE,
```

```
     +ALOBE(5)
      DATA TWOPI/6.2831853/
C     ROUTINE CALCULATES THE "OBSTACLE GAIN" CREATED BY THE RADIO WAVES
C     BEING DEFRACTED OVER THE HILL TOPS. A "KNIFE EDGE" OBSTACLE IS
C     ASSUMED, AND THE CALCULATIONS ARE PERFORMED USING THE FORMULAS
C     GIVEN BY ARMEL PICQUENARD'S BOOK "RADIO WAVE PROPAGATION",
C     SECTION 8.3.2.3 PAGES 294 THROUGH 296.
C     VARIABLES ARE:     H1    ELEVATION OF THE RADAR
C                        H0    ELEVATION OF THE HILL
C                        H2    ELEVATION OF THE TARGET
C                        D1    RANGE FROM THE RADAR TO THE HILL
C                        D2    RANGE FROM THE HILL TO THE TARGET
      RLAMDA=100.*EXP(W)
      H0=HW
      D1=WRANGE
      D2=PAR-D1
      H1=TMICA
      H2=SIZEB
      H1P=H0-TMICA
      H2P=H0-H2
C     CHECK TO SEE IF THE HILL IS THE HIGHEST OF THE THREE
C     IF IT ISN'T, USE AN OBSTRUCTION VALUE INDICATING AT THE EDGE
      IF (H0.GT.H1.AND.H0.GT.H2) GOTO 50
      OBGN=.90309
      RETURN
50    V0=H0*SQRT((2./RLAMDA)*((1./D1)+(1./D2)))
      OBGN=1.+20.*ALOG10(V0)-20.*ALOG10(SIN((TWOPI*H1*H1P)/(RLAMDA*D2)))
     -20.*ALOG10(SIN((TWOPI*H2*H2P)/(RLAMDA*D1)))
      RETURN
      END
      REAL FUNCTION PARS$(A$,LA,IDIM,IER)
C*****************************************************************************
C**                                                                         **
C**     A$ IS A REAL*8 CHARACTER STRING TO BE SEARCHED FOR THE              **
C**     OCCURANCE OF THE 1ST NON-LEADING BLANK.  A$ IS THEN SPLIT           **
C**     INTO TWO SUBSTRINGS, THE LEADING TOKEN (FIRST WORD) IS              **
C**     RETURNED AS THE FUNCTION VALUE AND THE REMAINDER IS PLACED          **
C**     BACK IN A$.                                                         **
C**                                                                         **
C**     LA IS AN INTEGER VARIABLE WHOSE VALUE IS THE NUMBER OF              **
C**     CHARACTERS IN A$ THAT ARE TO BE PARSED.  ON RETURN, LA IS           **
C**     THE NUMBER OF NON-BLANK CHARACTERS REMAINING IN A$ AFTER THE        **
C**     REMOVAL OF THE FIRST WORD.                                          **
C**                                                                         **
C**     IDIM IS AN INTEGER VARIABLE OR CONSTANT WHOSE VALUE IS THE          **
C**     SIZE OF THE STRING ARRAY TO BE PARSED EXACTLY AS DIMENSIONED        **
C**     IN THE CALLING PROGRAM.                                             **
C**                                                                         **
```

```
C**     IER IS AN INTEGER ERROR RETURN CODE EQUAL TO -1 IF LA IS          **
C**     .GT. 80 .OR. .GT. 8*IDIM .OR. .LT. 0.                             **
C**                                                                       **
C**     AN ATTEMPT TO PARSE A NULL STRING WILL RESULT IN A SPECIAL        **
C**     CHARACTER BEING PLACED IN THE 1ST POSITION OF A$.  A SUBSEQUENT**
C**     ATTEMPT TO REPARSE THIS STRING WILL RESULT IN A FATAL ERROR.      **
C**     THIS FEATURE IS INTENDED TO PREVENT UNCONTROLLED LOOPING OF THE**
C**     PARSE FUNCTION ON A NULL STRING.  THE SPECIAL CHARACTER USED      **
C**     IS KNOWN ONLY TO THIS ROUTINE AND MAY BE USED AS A REGULAR        **
C**     CHARACTER FOR IN ANY STRING OF LENGTH GREATER THAN ZERO.          **
C**                                                                       **
C**     PARS$ AND THE RESULT OF THE FUNCTION CALL TO PARS$ MUST BOTH      **
C**     BE TYPED REAL*8 IN THE CALLING PROGRAM.                           **
C**     ROUTINE WRITTEN BY MARK L. YOUNT                                  **
C**     USED IN ROUTINE SELECT TO PICK FILE FOR TERRAINE DATA             **
C**                                                                       **
C*************************************************************************
      IMPLICIT INTEGER(A-Z)
      REAL*8 PARS$
      COMMON/FILES/ IPRT,ICONIN,ICNOUT,IPRINT,IDSK(30)
      REAL*8 A$(IDIM),AA$(10),B$,BLANK8/'        '/
      LOGICAL*1 C$(80),D$(8),TEST1(2)
      LOGICAL*1 BLANK1/' '/
      LOGICAL*1 HALT/'!'/
      INTEGER*4 FUNC$/'PARS'/
      INTEGER*2 TEST2,BLANK2/'  '/,HALT2/'! '/
      EQUIVALENCE (C$(1),AA$(1)),(D$(1),B$),(TEST1(1),TEST2)
      DO 1 I=1,IDIM
         AA$(I) = A$(I)
         A$(I) = BLANK8
1     CONTINUE
      IF(IPRT.GE.10) WRITE(ICNOUT,200)LA,(C$(I),I=1,LA)
200   FORMAT(' TRACE ',I3,' PARS$   :   ',80A1)
      B$ = BLANK8
      IF(LA.GT.80.OR.LA.GT.8*IDIM.OR.LA.LT.0) GOTO 6000
C     CHECK TO SEE IF INPUT STRING IS NULL
      IF(LA.NE.0) GOTO 5
         IF(IPRT.GE.20) WRITE(ICNOUT,204)
204      FORMAT(' ATTEMPTED TO PARSE A NULL STRING.')
         TEST2 = BLANK2
         TEST1(1) = C$(1)
         IF(TEST2.EQ.HALT2) GOTO 6005
         C$(1)=HALT
         PARS$=B$
         LA=0
         RETURN
C     TRIM THE INPUT STRING OF LEADING BLANKS
5     IM=0
```

```
      DO 10 I=1,LA
         TEST2 = BLANK2
         TEST1(1) = C$(I)
         IF(TEST2.NE.BLANK2) GOTO 15
         IM=IM+1
10    CONTINUE
15    IF(IM.EQ.0) GOTO 25
         IF(IPRT.GE.20) WRITE(ICNOUT,201) IM
201      FORMAT(' FOUND',I3,' LEADING BLANKS IN INPUT STRING')
         IF(IM.LT.LA) GOTO 20
              LA=0
              PARS$=E$
              IF(IPRT.GE.20) WRITE(ICNOUT,202)
202           FORMAT(' FOUND INPUT STRING IS ALL BLANKS')
              RETURN
20       LEFT= LA-IM
         DO 23 I=1,LEFT
              C$(I)=C$(I+IM)
23       CONTINUE
         LA=LEFT
C     LOCATE THE FIRST NON-LEADING BLANK IN A$  (THEREBY DETERMINE LB)
25    LB=0
      DO 30 I=1,LA
         TEST2 = BLANK2
         TEST1(1) = C$(I)
         IF(TEST2.EQ.BLANK2) GOTO 35
         LB=LB+1
30    CONTINUE
C     CONSTRUCT TOKEN
35    DO 45 I=1,LB
         IF (I .GT. 8) GOTO 46
         D$(I)=C$(I)
45    CONTINUE
46    CONTINUE
      PARS$ = B$
      IF(IPRT.GE.20) WRITE(ICNOUT,205) LB,B$
205   FORMAT(' PARS$ FOUND TOKEN',I3,' "',A8)
C     REMOVE TOKEN FROM FRONT OF INPUT STRING
      LEFT=LA-LB-1
      IF(LEFT.GT.0) GOTO 50
         LA=0
         GOTO 75
50    DO 55 I=1,LEFT
         C$(I)=C$(I+LB+1)
         C$(I+LB+1) = BLANK1
55    CONTINUE
      LA=LEFT
      DO 56 I=1,IDIM
```

```
         A$(I) = AA$(I)
56    CONTINUE
C     CHECK A$ FOR TRAILING BLANKS
      IF(LA.EQ.0) GOTO 75
58    IM=0
      DO 60 I=1,LA
         INDEX=LA-I+1
         TEST2 = BLANK2
         TEST1(1) = C$(INDEX)
         IF(TEST2.NE.BLANK2) GOTO 65
         IM=IM+1
60    CONTINUE
65    IF(IM.EQ.0) GOTO 75
         IF(IPRT.GE.20) WRITE(ICNOUT,207) IM
207      FORMAT(' FOUND',I3,' TRAILING BLANKS IN INPUT STRING')
         IF(IM.LT.LA) GOTO 70
            LA=0
            IF(IPRT.GE.20) WRITE(ICNOUT,208)
208         FORMAT(' FOUND REMAINING STRING IS ALL BLANKS')
            RETURN
70       LA=LA-IM
75    IER=0
      IF(IPRT.GE.20.AND.LA.EQ.0) WRITE(ICNOUT,209)
209   FORMAT(' REMAINING STRING AFTER PARSE FUNCTION IS NULL')
      RETURN
C     ERROR HANDLING SECTION FOLLOWS
6000  WRITE(ICNOUT,6001) FUNC$
6001  FORMAT(' *** STRING LENGTH ERROR *** ',A4)
      PARS$=BLANK8
      IER = -1
      RETURN
6005  WRITE(ICNOUT,6006)
6006  FORMAT(' *** FATAL ERROR: ATTEMPTED TO PARSE A NULL STRING TWICE')
      STOP
      END
      SUBROUTINE PD2SE (SE,NP,IPF,PDET)
      REAL PF(15,4) /3.8,1.9,0.8,0.0,-0.5,-1.0,-1.3,-1.8,-2.0,-2.2,-4.0
     +,-5.5,-6.5,-7.1,-7.6,5.1,3.1,2.0,1.2,0.8,0.2,-0.2,-0.5,-0.8,-1.0,
     +-2.9,-4.5,-5.5,-6.0,-6.4,6.1,4.0,3.0,2.2,1.7,1.1,0.8,0.5,0.0,-0.1,
     +-2.0,-3.5,-4.5,-5.2,-5.5,7.0,4.9,3.8,3.0,2.3,1.9,1.4,1.0,0.8,0.5,
     +-1.3,-3.0,-4.0,-4.5,-5.5/
C     ROUTINE CALCULATES SIGNAL EXCESS REQUIRED TO GIVE A SPECIFIED
C     PROBABILITY OF DETECTION, BASED ON THE NUMBER OF PULSES PER SWEEP
C     AND A SPECIFIED PROBABILITY OF FAILURE (TAKEN FROM BELOW).
C     IPF(1) IS 10E-4
C     IPF(2) IS 10E-6
C     IPF(3) IS 10E-8
C     IPF(4) IS 10E-10
```

```
      I=15
      IF (NP.LT.900)  I=14
      IF (NP.LT.700)  I=13
      IF (NP.LT.500)  I=12
      IF (NP.LT.300)  I=11
      IF (NP.LT.150)  I=NP/10
      IF (I.LT.1)  I=1
      RMU=PF(I,IPF)
C     USING BLAKE'S RESULTS OF NRL RPT 6930, AS IN W.E.S.
      CALL MDNRIS (PDET,Z,IER)
      SE=7.*Z+RMU
      RETURN
      END
      SUBROUTINE RANGE (X1,Y1,X2,Y2,RANGE)
C     ROUTINE FINDS RANGE BETWEEN (X1,Y1) AND (X2,Y2) IN A PLANE
      RANGE=SQRT((X2-X1)**2+(Y2-Y1)**2)
      RETURN
      END
      SUBROUTINE RMAP(A,N,M,SFNM)
      DIMENSION A(N,M),BV(21)
      REAL*8 CR
C     RMAP IS A VERSION OF TMAP MODIFIED TO ALLOW THE USE OF SPECIAL
C     SYMBOLS. TMAP HAS BEEN SUBMITTED FOR THE NONIMSL LIBRARY AT NPS
C     ROUTINE INTERACTIVELY TAKES AN ARRAY AND PREPARES A CONTOUR MAP
C     FOR THE VICINITY OF A GIVEN POINT. THE OUTPUT IS ON A TERMINAL
C     OR ON THE PRINTER, AT THE OPTION OF THE USER, INTERACTIVELY
C     TAKING INPUT FROM A KEYBOARD.
C     PASSED ARGUMENTS: A IS THE ARRAY TO BE PLOTTED
C                       N AND M ARE ITS DIMENSION
C                       SFNM IS THE NUMBER OF NAUTICAL MILES BETWEEN
C                       SAMPLED POINTS
C     OTHER ARGUMENTS ARE REQUESTED AT THE TERMINAL
C     LARGE AMOUNTS OF VIRTUAL STORAGE ARE REQUIRED FOR LARGE ARRAYS
C     UP TO 1M MAY BE REQUIRED FOR A 400X400 ARRAY.
C     PROGRAM IS A MODIFIED VERSION OF PROFESSOR GILLES CANTIN'S
C     PROGRAM CTRMAP VERSION OF OCT 1, 1969, ADAPTED FOR TERMINAL USE.
C     JAMES W. MERITT, LT, USN
      CALL PREMAP (A,N,M,SCF,BV,SFNM)
      WRITE (6,10)
10    FORMAT (' SCREEN DISPLAY DESIRED?')
      CALL ANSWER (K)
      IF (K.NE.1) GOTO 20
100   CONTINUE
      CALL PSTMAP (A,N,M,SFNM)
      WRITE (6,1)
1     FORMAT (' ANOTHER?')
      CALL ANSWER (K)
      IF (K.EQ.1) GOTO 100
```

```
20      WRITE (6,2)
2       FORMAT (' PRINTED VERSION OF ARRAY DESIRED?')
        CALL ANSWER (KL)
        IF (KL.EQ.1) CALL PRTMAP (A,N,M,BV,SCF,SFNM)
        DO 60 I=1,N
        DO 61 J=1,M
61      IF (A(I,J).GE.0.0)  A(I,J)=A(I,J)/SCF
60      CONTINUE
        RETURN
        END
        SUBROUTINE PREMAP(A,N,M,SCF,BV,SFNM)
C          ROUTINE PREPARES THE ARRAY FOR PLOTTING AND PRINTS THE
C          SCALE ON THE TERMINAL.
        DIMENSION BV(21),A(N,M)
        CALL PRTCMS ('CLRSCRN')
        AMIN=0.0
        AMAX=-1.E+70
        DO 11 I=1,N
        DO 10 J=1,M
   10   AMAX=AMAX1(AMAX,A(I,J))
   11   CONTINUE
        RGE=AMAX
        IF(ABS(RGE)-1.0E-10)  12,12,13
   12   WRITE(6,1000)  SFNM
        WRITE(6,1400)  RGE,AMAX,AMIN
1000    FORMAT ('1THERE ARE ',F6.2,'NM BETWEEN POINTS')
 1400   FORMAT(//,5X,13H THE RANGE IS,E15.6,/,5X,13H    MAXIMUM IS,E15.6,/,
      15X,13H    MINIMUM IS,E15.6)
        SCF=1.
        RETURN
   13   CONTINUE
        SCF=40./AMAX
        DO 21 I=1,N
        DO 20 J=1,M
   20   IF (A(I,J).GE.0.0)  A(I,J)=SCF*A(I,J)
   21   CONTINUE
        DO 30 I=1,21
        AI=FLOAT (I-1)
   30   BV(I)=(2.*AI/SCF)+AMIN
        WRITE(6,1050)  SFNM
        WRITE(6,1300)  BV(1),BV(1),BV(21)
        WRITE(6,1100)  BV(2),BV(3),BV(4),BV(5),BV(6)
        WRITE(6,1200)  BV(7),BV(8),BV(9),BV(10),BV(11)
        WRITE(6,1210)  BV(12),BV(13),BV(14),BV(15),BV(16)
        WRITE(6,1220)  BV(17),BV(18),BV(19),BV(20),BV(21)
        WRITE (6,4000)
4000    FORMAT (5X,' $=RADAR         *=MASKED')
 1050   FORMAT(//'1THERE ARE ',F6.2,'NM BETWEEN POINTS')
```

```
1100 FORMAT(5X,3H A=,F8.3,3X,3H B=,F8.3,3X,3H C=,F8.3,3X,3H D=,F8.3,
    13X,3H E=,F8.3)
1200 FORMAT(5X,3H F=,F8.3,3X,3H G=,F8.3,3X,3H H=,F8.3,3X,3H I=,F8.3,
    13X,3H J=,F8.3)
1210 FORMAT(5X,3H Q=,F8.3,3X,3H R=,F8.3,3X,3H S=,F8.3,3X,3H T=,F8.3,
    13X,3H U=,F8.3)
1220 FORMAT(5X,3H V=,F8.3,3X,3H W=,F8.3,3X,3H X=,F8.3,3X,3H Y=,F8.3,
    13X,3H Z=,F8.3)
1300 FORMAT(5X,3H O=,F10.6,5X,7H RANGE(,E15.6,5X,E15.6,2H ))
2000 FORMAT(2X,115A1)
     RETURN
     END
     SUBROUTINE PSTMAP(A,N,M,SFNM)
C        SUBROUTINE PLOTS THE CONTOUR MAP ON THE SCREEN
     DIMENSION LINE(80),ISYMB(42),BV(21),A(N,M)
     DATA ISYMB/1H ,1H ,1H ,1HA,1H ,1HB,1H ,1HC,1H ,1HD,1H ,1HE
    1,1H ,1HF,1H ,1HG,1H ,1HH,1H ,1HI,1H ,1HJ,1H ,1HQ,1H ,1HR,1H ,1HS,
    21H ,1HT,1H ,1HU,1H ,1HV,1H ,1HW,1H ,1HX,1H ,1HY,1H ,1HZ/
     DATA IBLK/1H /,IHIDE/1H*/,MSHIP/1H$/,KOAST/1H//
     WRITE (6,1)
1    FORMAT (' ENTER POINT OF INTEREST AS NM SOUTH THEN EAST OF ',
    +'REFERENCE POINT')
     READ (5,*) RX,RY
     IX=INT(RX/SFNM)
     IY=INT(RY/SFNM)
     IX=MAX(IX,1)
     IY=MAX(IY,1)
     IX=MIN(IX,N)
     IY=MIN(IY,M)
     IXT=IX-10
     IYL=IY-40
     IF (IXT.LE.0) IXT=1
     IF (IYL.LE.0) IYL=1
     CALL PRTCMS ('CLRSCRN')
     IXB=MIN(N,IXT+20)
     IYR=MIN(M,IYL+80)
     WRITE (6,200) RX,RY
200  FORMAT (' PLOT CENTERED ON ',F6.2,'NM SOUTH AND ',F6.2,'NM EAST')
     DO 50 K=IXT,IXB
     DO 40 J=IYL,IYR
     AJ=A(K,J)+2.50001
     JJ=INT(AJ)
     JK=J-IYL+1
     IF (JJ.GT.0) LINE(JK)=ISYMB(JJ)
     IF (JJ.EQ.0) LINE(JK)=IHIDE
     IF (JJ.EQ.-1) LINE(JK)=MSHIP
     IF (JJ.EQ.-2) LINE(JK)=KOAST
  40 CONTINUE
```

```
   46 CONTINUE
      WRITE(6,2000)  (LINE(L),L=1,80)
      DO 45 I=1,80
   45 LINE(I)=IBLK
   50 CONTINUE
 2000 FORMAT(' ',80A1)
      RETURN
      END
      SUBROUTINE PRTMAP(A,N,M,BV,SCF,SFNM)
C        SUBEROUTINE PLOTS CONTOUR MAP ON PRINTER. IF ARRAY IS OVER
C        100 CHARACTERS WIDE, IT IS PLOTTED IN STRIPS.
      DIMENSION LINE(100),ISYMB(42),BV(21),A(N,M)
      DATA ISYMB/1H ,1H ,1H ,1HA,1H ,1HB,1H ,1HC,1H ,1HD,1H ,1HE
     1,1H ,1HF,1H ,1HG,1H ,1HH,1H ,1HI,1H ,1HJ,1H ,1HQ,1H ,1HR,1H ,1HS,
     21H ,1HT,1H ,1HU,1H ,1HV,1H ,1HW,1H ,1HX,1H ,1HY,1H ,1HZ/
      DATA IBLK/1H /,IHIDE/1H*/,MSHIP/1H$/,KOAST/1H//
      CALL FRTCMS ('FILEDEF','08','PRINT','(','RECFM','FA','BLOCK',
     +'133')
      WRITE (8,1)
1     FORMAT ('1CONTOUR MAP OF ENTIRE DATA SET:'///)
      WRITE(8,1050) SFNM
      WRITE(8,1300) BV(1),BV(1),BV(21)
      WRITE(8,1100) BV(2),BV(3),BV(4),BV(5),BV(8)
      WRITE(8,1200) BV(7),BV(8),BV(9),BV(10),BV(11)
      WRITE(8,1210) BV(12),BV(13),BV(14),BV(15),BV(16)
      WRITE(8,1220) BV(17),BV(18),BV(19),BV(20),BV(21)
      WRITE (8,4000)
4000  FORMAT (5X,' $=RADAR        *=MASKED ')
 1050 FORMAT(//' THERE ARE ',F4.2,'NM BETWEEN POINTS ')
 1100 FORMAT(5X,3H A=,F8.3,3X,3H B=,F8.3,3X,3H C=,F8.3,3X,3H D=,F8.3,
     13X,3H E=,F8.3)
 1200 FORMAT(5X,3H F=,F8.3,3X,3H G=,F8.3,3X,3H H=,F8.3,3X,3H I=,F8.3,
     13X,3H J=,F8.3)
 1210 FORMAT(5X,3H Q=,F8.3,3X,3H R=,F8.3,3X,3H S=,F8.3,3X,3H T=,F8.3,
     13X,3H U=,F8.3)
 1220 FORMAT(5X,3H V=,F8.3,3X,3H W=,F8.3,3X,3H X=,F8.3,3X,3H Y=,F8.3,
     13X,3H Z=,F8.3)
 1300 FORMAT(5X,3H O=,F10.6,5X,7H RANGE(,E15.6,5X,E15.6,2H ))
      IYL=1
      IYR=100
1000  WRITE (8,200) IYL,IYR
200   FORMAT ('1PLOT FROM ',I3,' TO ',I3)
      WRITE (8,3000)
3000  FORMAT ('                    1         2         3         4',
     +'        5         6         7         8         9         0')
      DO 50 K=1,N
      DO 40 J=IYL,IYR
      JK=J-IYL+1
```

```
      AJ=A(K,J)+2.50001
      JJ=INT(AJ)
      IF (JJ.GT.0) LINE(JK)=ISYMB(JJ)
      IF (JJ.EQ.0) LINE(JK)=IHIDE
      IF (JJ.EQ.-1) LINE(JK)=MSHIP
      IF (JJ.EQ.-2) LINE(JK)=KOAST
   40 CONTINUE
   46 CONTINUE
      WRITE(8,2000) K,(LINE(L),L=1,100)
      DO 45 I=1,100
   45 LINE(I)=IBLK
50    CONTINUE
      IYL=IYR+1
      IYR=MIN(IYL+100,M)
      IF (IYL.LT.IYR) GOTO 1000
 2000 FORMAT(' ',I5,' ',100A1)
      WRITE (6,3001)
3001  FORMAT (' CONTOUR MAP OF ARRAY SENT TO PRINTER')
      RETURN
      END
      SUBROUTINE SELECT
      REAL*8 FILE$(3),  FNAME$,  FTYPE$,  FMODE$,  FILES$(3),
     *   PARS$,  A1/'A1'/,  SEC, FILE/'07'/,  FNUM$
C     ROUTINE ADAPTED FROM ONE PROVIDED BY MARK L. YOUNT, USED IN
C     CONJUNCTION WITH PAR$ TO DEFINE DATA FILES
      REWIND 7
      WRITE(6,205)
205   FORMAT(6X,'ENTER A FILE IDENTIFICATION <FN FT FM>')
      READ(5,100) FILE$
100   FORMAT(3A8)
      LA = 24
      FNAME$ = PARS$(FILE$,LA,3,IER)
      IF (IER .NE. 0) STOP
      FTYPE$ = PARS$(FILE$,LA,3,IER)
      IF (IER .NE. 0) STOP
      IF (LA .EQ. 0) GOTO 10
      FMODE$ = PARS$(FILE$,LA,3,IER)
      IF (IER .NE. 0) STOP
      GOTO 20
10    CONTINUE
      WRITE(6,200)
200   FORMAT(//,10X,'NO FILEMODE WAS ENTERED, A1 ASSUMED')
      FMODE$ = A1
20    CONTINUE
      CALL PRTCMS('FILEDEF',FILE,'DISK',FNAME$,FTYPE$,FMODE$)
      RETURN
      END
      SUBROUTINE SETUP
```

```
      REAL*8 FN,FT
      COMMON /IPRT/ IPRT
      COMMON /HILLS/ XC(100),YC(100),PEAK(100),SX(100),SY(100),RHO(100)
      COMMON /HILLS/ SCALE(100),TWORHO(100),TWOSCL(100),BASE
      COMMON /HILLS/ NHILLS
      COMMON /COUNTR/KH,KHW,KV,KN,KGRS,KELL,KINT
      COMMON /GRID/ LST(10,10),NHL(10,10),LISTH(450),KHREP(100),KTREP
      COMMON /HILL/ XMC(100),YMC(100)
C     SUBROUTINE READS IN THE TERRAIN DATA FROM A SPECIFIED DATA FILE
      IF(IPRT.GE.10) WRITE(6,388)
388   FORMAT(' ************************ENTERED SUBROUTINE SETUP******')
      CALL SELECT
      L = 7
      READ(L,*) NHILLS
C     NHILLS IS THE TOTAL NUMBER OF HILLS
      READ(L,*) BASE
C     BASE IS THE SURFACE REFERENCE PLANE, SEAL LEVEL FOR ME
      DO 50 I=1,NHILLS
      READ(L,*) XC(I),YC(I),PEAK(I),SX(I),SY(I),RHO(I)
C     XC(I) AND YC(I) ARE THE X AND Y COORDINATES OF THE CENTER OF HILL
C     PEAK(I) IS THE MAXIMUM ELEVATION OF HILL I
C     SX(I) AND SY(I) ARE THE STANDARD DEVIATIONS IN X AND Y OF HILL I
C     RHO(I) IS THE CORRELATION BETWEEN X AND Y FOR HILL I
50    CONTINUE
      READ(L,*)LST
C     LST IS A POINTER FOR WHERE TO START ON LISTH
      READ(L,*)NHL
C     NHL IS AN ARRAY HOLDING HOW MANY HILLS ARE IN THE CORRESPONDING
C     GRID SQUARE
      READ(L,*)NHTOT
C     NHTOT IS THE TOTAL NUMBER OF HILLS ENTERED IN LISTH (LESS THAN 450
      READ(L,*) (LISTH(I),I=1,NHTOT)
C     A LIST OF WHICH HILLS AFFECT WHICH GRIDSQUARE
   65 DO 100 I=1,NHILLS
      XMC(I)=XC(I)
      YMC(I)=YC(I)
      XC(I)=XC(I)*1829.27
      YC(I)=YC(I)*1829.27
      TWORHO(I)=2.*RHO(I)
      SCALE(I)=-1./(2.*(1.-RHO(I)**2))
      TWOSCL(I)=2.*SCALE(I)
      KHREP(I)=-2147483600
C  ALL VALUES NOW IN METERS ON 0 -- 10,000 GRID
100   CONTINUE
      KTREP=-2147483600
      KH=0
      KHW=0
      KV=0
```

```
      KN=0
      KGRS=0
      KELL=0
      KINT=0
      IF(IPRT.GE.10) WRITE(6,389)
389   FORMAT(' ************************LEAVING SUBROUTINE SETUP******')
      RETURN
      END
      SUBROUTINE SE2PD (SE,NP,IPF,PDET)
      REAL PP(15,4) /3.8,1.9,0.8,0.0,-0.5,-1.0,-1.3,-1.8,-2.0,-2.2,-4.0
     +,-5.5,-6.5,-7.1,-7.6,5.1,3.1,2.0,1.2,0.8,0.2,-0.2,-0.5,-0.8,-1.0,
     +-2.9,-4.5,-5.5,-6.0,-6.4,6.1,4.0,3.0,2.2,1.7,1.1,0.8,0.5,0.0,-0.1,
     +-2.0,-3.5,-4.5,-5.2,-5.5,7.0,4.9,3.8,3.0,2.3,1.9,1.4,1.0,0.8,0.5,
     +-1.3,-3.0,-4.0,-4.5,-5.5/
C     ROUTINE CALCULATES PROBABILITY OF DETECTION , GIVEN A SPECIFIED
C     SIGNAL EXCESS, BASED ON THE NUMBER OF PULSES PER SWEEP
C     AND A SPECIFIED PROBABILITY OF FAILURE (TAKEN FROM BELOW).
C     IPF(1) IS 10E-4
C     IPF(2) IS 10E-6
C     IPF(3) IS 10E-8
C     IPF(4) IS 10E-10
      I=15
      IF (NP.LT.900) I=14
      IF (NP.LT.700) I=13
      IF (NP.LT.500) I=12
      IF (NP.LT.300) I=11
      IF (NP.LT.150) I=NP/10
      IF (I.LT.1) I=1
      RMU=PP(I,IPF)
C     USING BLAKE'S RESULTS OF NRL RPT 6930, AS IN W.E.S.
      Z=(SE-RMU)/7.
      PDET=1.0-.50*(ERF(-Z*.7071067690)+1.00)
      RETURN
      END
```

APPENDIX B

SUBROUTINE DIRECTORY

The following subroutines are used in this project:

A. BEACH

This subroutine determines if a point of land is adjacent to the sea.

IX and IY are the X and Y coordinates in array A

A is the map array, dimensioned N by M

KOAST is the returned value

B. BRTN

This routine calculates the geometric cross section of an area of land the size of a resolution cell which may contain a target.

X1,Y1 are the position of the radar

X2,Y2 are the position of the beach

RRES is the range resolution

ARES is the angular resolution

TMAC is the terrain elevation

ECS is the effective radar cross section of the beach

C. ECURVE

This subroutine computes the elevation reduction caused by the earth's curvature present at a given range.

EER is the effective earth radius in meters

RANGE is the distance traveled along the earth

DROP is the loss in elevation resulting from the earth's curvature

D. ELEV

This routine determines the elevation at a given location.

X,Y are the coordinates of the point

TMAC is the returned elevation

E. ELEVG

This routine is similiar to ELEV, but it also calculates the gradient components.

GX AND GY are the calculated components of the gradient.

F. GETSE

This routine processes radar data to compute the signal excess returned to the radar from a contact under the specified conditions.

SE is the returned signal excess

G. INPUT

This routine reads in the radar, target, environmental, and detection data, either from the terminal or from a data file. (the variables are listed in order of appearance in the subroutine)

RDR$	name of the radar system
PTR	peak transmitted power
B	receiver bandwidth
PRR	pulse repetition rate
BW	horizontal beam width
BV	vertical beam width
ARES	angular resolution
G	antenna gain
SW	angular width of swept sector
ARR	scan rate
PL	pulse length
FREQ	frequency
HR	radar antenna altitude
TMICA	radar antenna altitude
RX,RY	coordinates of radar
W	wavelength
NP	number of pulses illuminating a target per sweep
TGT$	identifier for target

HT	vertical size of target
SIZEB	vertical size of target
DISP	target maximum displacement
TCS	target radar cross section
ISTR	ducting strength code letter
IPF	probablity of failure code letter
PDET	required probability of detection for a single sweep
SE	signal excess required to give a desired PDET
HW	significant wave height
C	clutter factor
RL	system loss factor
RNF	receiver noise figure
RMIN	minimum range
RRES	range resolution
RMAX	maximum unambigious range
RHORIZ	radar horizon

H. INTRO

This is the initial page display.

I. KOVER

This routine is only used internally by LOS

J. LAND

This subroutine determines if a point would be masked by return from land in either the main beam adjacent to the given point, or by land at the appropriate point in a side lobe.

MASK is the returned value, one if there is masking, zero otherwise.

K. LOS

This routine calculates the line-of-sight in terms of a fraction visible for observer-target pairs. (the variables are listed in the order of appearance in the subroutine)

XA,YA (XB,YB) are the X,Y coordinates on the field for A and B.

TMACA (TMACB) are terrain elevation for A (B)

TMICA (TMICB) elevation of A (B).

SIZEA (SIZEB) vertical dimension of A (B).

LATOB (LBTOA) indicator variable for LOS calls.

HHW is the height of the obstructing hill (if any).

WRANGE is the range from the radar to the obstructing hill (if any).

VISFRA (VISFRB) fraction of SIZEA(SIZEB) which can be seen by B(A).

L. OBGAIN

This routine calculates the "obstacle gain created by the radio waves being defracted over hill tops.

H1	elevation of the radar
H0	elevation of the hill
H2	elevation of the target
D1	range from the radar to the hill
D2	range from the hill to the target
RLAMDA	wavelength
OBGN	returned obstacle gain

M. $PARS

This routine is by Mark Yount. It splits a double-precision string down into its separate words.

N. RANGE

This routine finds the range between (X1,Y1) and (X2,Y2) in a plane.

RANGE is returned.

O. RMAP

This routine prepares contour maps with special symbols to be displayed either on the terminal, in response to locations keyed in, or on a line printer. RMAP is composed of three subroutines: PREMAP, PSTMAP, and PRTMAP.

A   is the array to be plotted, dimensioned N by M

SPNM   is the number of nautical miles between sample points on the grid.

P. SELECT

This routine defines the data files so that the program may access them. Written with assistance from Mark L. Yount.

Q. SETUP

This routine reads in the terrain data from a predesignated data file. (the variables are listed in the order they appear in the subroutine)

NHILLS total number of hills

BASE   surface reference plane

XC(I) and YC(I) are the x,y coordinates of the center of the hill

PEAK(I) is the maximum elevation of hill I.

SX(I) and SY(I) are the standard deviations in X and Y of hill I.

RHO(I)	correlation between X and Y for hill I
LST	pointer on where to start reading on LISTH
NHL	array holding how many hills are in corresponding grid square
NHTOT	total number of hills in LISTH
LISTH	a list of which hills affect which gridsquare

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