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Specification for a Standard Radar Sea Clutter Model

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ADMINISTRATIVE INFORMATION

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1.0 INTRODUCTION

The purpose of this report is to document a radar sea clutter model for inclusion as a Navy standard model in the Oceanographic and Atmospheric Master Library (OAML).

The generalized form of the radar equation can be written as

$$P_r = \frac{P_t G^2 \lambda^2 L_s}{(4\pi)^3 R^4} \sigma_c F^4 \quad (W) \quad (1)$$

where P_r is power received, P_t is transmitted power, G is antenna gain, λ is radar wavelength, L_s is system losses, R is range, σ_c is average clutter cross section, and F is the pattern propagation factor. If the antenna pattern effects are separated from F , Eq. 1 becomes

$$P_r = \frac{P_t G^2 \lambda^2 L_s f(\alpha)^4}{(4\pi)^3 R^4} \sigma_c F^4 \quad (W) \quad (2)$$

where $f(\alpha)$ is the antenna pattern factor for angle α , and F is now the propagation factor. Sea clutter cross section can be factored further by

$$\sigma_c = \sigma^0 A_c \quad (m^2) \quad (3)$$

where σ^0 is normalized radar reflectivity of the sea surface (m^2/m^2), and A_c is the radar's clutter resolution cell

$$A_c = \frac{c\tau}{2} \frac{\theta}{2 \ln(2)} R \sec(\psi) \quad (m^2) \quad (4)$$

In Eq. 4, c is the speed of light, τ is the radar's compressed pulse length (or pulse length if pulse compression is not used), θ is the horizontal beamwidth (one-way, 3 dB), and ψ is grazing angle at the surface. For angles of interest here, $\psi \leq 10$ degrees and $\sec(\psi) \approx 1$. In the type of semiempirical sea clutter model being proposed here, the propagation factor is considered to be included in the models for σ_c ; that is, $\sigma^0 A_c F^4$ can be thought of as effective cross section, σ_c . Thus, the radar equation is now

$$P_r = \frac{P_t G^2 \lambda^2 L_s f(\alpha)^4}{(4\pi)^3 R^4} \sigma_c \quad (W) \quad (5)$$

and all of the environmental and propagation considerations are contained in the model of σ^0 . An existing normalized sea clutter model¹ has been shown capable of approximating observed clutter data if grazing angles are calculated based upon typical surface-layer refractive conditions over the ocean.² The model proposed here combines this adaptation of the σ^0 model with the radar resolution cell, A_c , to provide a model of σ_c in Eq. 5 versus range under varying propagation conditions for typical radar frequencies.

In section 2.0, the inputs, outputs, and limits of the sea clutter model are defined. In section 3.0, the model is described in detail. In section 4.0, test data are shown to verify the proper operation of the computer program listed in the appendix.

2.0 INPUTS, OUTPUTS, AND LIMITS

Environmental measurements and radar system parameters are required to calculate the average sea clutter radar cross section as the output. The environmental input parameters are summarized in Table 1.

Table 1. Environmental input parameters.

Parameter	Limits	Precision
Evaporation duct height	0 to 40 m	0.1 m
Modified refractivity profile	0 to 10,000 m	1 m
	0 to 2000 <i>M</i>	1 <i>M</i>
Wind speed	0 to 25 m/s	1 m/s
Wind direction relative to antenna boresight	0 to 180 deg	5 deg

2.1 ENVIRONMENTAL PARAMETERS

2.1.1 Evaporation Duct Height

The evaporation duct height can be calculated from measurements of wind speed, air temperature, relative humidity, and sea surface temperature,³ or derived from a statistical data base.⁴ The evaporation duct height is used to generate a modified refractivity profile for the atmospheric surface layer. The *M*-profile is subsequently used in determining grazing angles at the sea surface for frequencies of 2 GHz and greater. The evaporation duct height is limited to 0 to 40 meters.

2.1.2 Modified Refractivity Profile

The modified refractivity profile is represented by couplets of height in meters and refractivity in *M*-units from the surface to some height greater than the radar altitude. This profile, which can be derived from radiosonde or refractometer measurements or a statistical data base,⁴ is used in the model to calculate an effective earth radius for the determination of grazing angles at the sea surface for frequencies less than 2 GHz.

2.1.3 Wind Speed and Direction

Wind speed and direction can be measured by any typical cup or aerovane anemometer. The measurement should be made in a location that is representative of the wind flow over the ocean at the standard anemometer height (19.5 meters). The valid range of the windspeed is 0 to 25 m/s. Wind direction for the sea clutter model is defined relative to the direction in which the radar antenna is pointing; the measured wind direction must be converted to this definition in the range of 0 to 180 degrees. Wind speed is used to calculate a wind speed factor in the sea clutter model. Under the assumption of a fully risen sea and steady-state conditions, wind speed and wave height are highly correlated, and wind speed is used to calculate an average wave height for the interference factor. Under transient conditions, wave height and wind speed may not be well correlated, and the model could be modified to accept both wind speed and average wave height as inputs.

Wind direction relative to the radar antenna boresight is used to calculate an upwind/downwind factor that varies from a maximum looking into the wind to a minimum looking with the wind. An intermediate clutter level calculated in the crosswind direction (90 degrees) yields a level that is $\approx \pm 5$ dB of the clutter level in the upwind/downwind directions.

2.2 RADAR PARAMETERS

The required radar system parameters are summarized in Table 2. Antenna height, polarization, and radar frequency are used in the calculations of normalized radar cross section, σ^0 . The horizontal beamwidth and compressed pulse length are used in the calculation of the radar clutter resolution cell. If the radar receiver does not use pulse compression, the pulse length is used.

Table 2. Radar system parameters.

Parameter	Limits	Precision
Antenna height	1 to 10000 m	1 m
Radar frequency	100 to 20000 MHz	1 MHz
Antenna polarization	H, V, C	-
Horizontal beamwidth	>0 to 45 deg	0.1 deg
Compressed pulse length	>0 to 1000 μ s	0.1 μ s
Maximum range	500 km	1 km

* H = horizontal, V = vertical, C = circular.

2.3 OUTPUT

The output of the sea clutter model is clutter level in decibels relative to a 1 m² target versus range in kilometers.

3.0 MODEL

The sea clutter model is composed of two main functions. First, grazing angle at the sea surface, ψ , is determined from inputs of evaporation duct height, δ , effective earth radius, a_e , radar antenna height, H_t , and radar frequency, f . Next, normalized radar cross section, σ^0 , is calculated from inputs of grazing angle, wind speed, V_w , wind direction relative to the antenna, ϕ , radar frequency, and antenna polarization. The normalized radar cross section can then be used directly to calculate average radar cross section, σ_c , versus range out to the maximum range specified.

3.1 GRAZING ANGLE AT SEA SURFACE

At radar frequencies less than 2000 MHz, the effective earth radius is assumed to be the dominant factor in determining grazing angle versus range. The minimum grazing angle allowed is 1.745×10^{-3} radians (0.1 degree); the maximum grazing angle is 1.745×10^{-1} radians (10 degrees). The range, r , in kilometers at which a specific grazing angle occurs is determined from the quadratic formula

$$r = \frac{-b + \sqrt{b^2 - 4ac}}{2a} \quad (\text{km}) \quad (6)$$

with

$$a = 1$$

$$b = 2a_e\psi$$

$$c = -2a_e H_t / 1000$$

where a_e is in kilometers, ψ is in radians, and H_t is in meters. The effective earth radius is determined by using subroutines MFROF, INSRT, PUSH, and GETK from the standard propagation model.⁶ The elevation angle, α , at the antenna that corresponds to a given range is

$$\alpha = -\frac{H_t}{1000r} - \frac{r}{2a_e} \quad (\text{rad}) \quad (7)$$

Grazing angles at ranges intermediate to those corresponding to the maximum and minimum grazing angles are determined by

$$\psi = \frac{H_t}{1000r} + \frac{r}{2a_e} \quad (\text{rad}) \quad (8)$$

where range increments are 1/100 of the maximum range.

At radar frequencies of 2000 MHz and greater, the evaporation duct can have a significant effect on the variation of grazing angle versus range. Instead of an effective earth radius being used in the ray-optics calculations, a refractive profile for the evaporation duct must be generated. The M -value at the sea surface, M_0 , is arbitrarily set equal to 340, and the profile is calculated from

$$M(z) = M_0 + 0.125z - 0.125\delta \ln \left(\frac{z + z_0}{z_c} \right) \quad (9)$$

where \ln is the natural logarithm and

$$z = e^k, \quad k = -2, -1, 0, 1, 2, 3, 4$$

for heights, z , above the surface. The aerodynamic roughness of the sea surface, z_0 , is assumed constant at 0.00015 meter. The minimum value in the evaporation duct profile occurs at the evaporation duct height (where $z = \delta$) and must also be included in the profile. (Note that Eq. 9 can be used to generate a profile with subrefractive layers if a negative δ is entered. The physical meaning of negative δ is the height at which dM/dz reaches a value of $+0.250M/m$. However, the evaporation duct model³ has been arbitrarily limited to positive duct heights.) To complete the profile and as a convenience for ray-optics calculations, the height of the radar is included in the height array and the M -value at the height of the radar is included in the M -array. This M -value is determined by linear interpolation between adjacent levels or extrapolation at 0.118 M/m above the last level in the profile.

The minimum elevation angle allowed is -1.745×10^{-1} radians (-10 degrees). The maximum elevation angle is calculated from

$$\alpha_{\max} = -[2 \times 10^{-6}(M_{ht} - M_{\min})]^{1/2} - 1 \times 10^{-6} \quad (\text{rad}) \quad (10)$$

where M_{ht} is the value of M at the radar antenna height and M_{\min} is the minimum value of M_{\min} in the profile below the height of the radar. If the radar height is less than the evaporation duct height, then

$$\alpha_{\max} = -[2 \times 10^{-6}(M_{ht} - M_{\delta})]^{1/2} - 1 \times 10^{-6} \quad (\text{rad}) \quad (11)$$

where M_{δ} is the value of M at the evaporation duct height. The grazing angle corresponding to each elevation angle is

$$\psi = [\alpha^2 - 2 \times 10^{-6}(M_{ht} - M_0)]^{1/2} \quad (\text{rad}) \quad (12)$$

The elevation angle is gradually decreased between the maximum and minimum angles according to

$$\Delta \alpha = \frac{\alpha_{\max} - \alpha_{\min}}{d} \quad (\text{rad}) \quad (13)$$

where d has a value dependent upon the last value of ψ :

$\psi < 0.0175$	$d = 200$
$0.0175 \leq \psi < 0.08$	$d = 20$
$\psi \leq 0.08$	$d = 4$

The range corresponding to each elevation angle (and grazing angle) is determined by tracing a ray from the radar antenna height through the successive layers of the M -profile to the surface. For downgoing rays ($\alpha < 0$), the angle, α' , at the base of the layer is

$$\alpha' = -[\alpha^2 + 2 \times 10^{-6}dMdh(h_{i-1} - h_i)]^{1/2} \quad (\text{rad}) \quad (14)$$

and the range, r' , traveled is

$$r' = r + \frac{\alpha' - \alpha}{1 \times 10^{-3} dMdh} \quad (\text{rad}) \quad (15)$$

where $dMdh$ is the refractive gradient (M/m) of the layer. If the radar antenna height is less than the evaporation duct height, the rays are initially upgoing and are traced to the level of the evaporation duct height. For upgoing rays, the elevation angle at the top of the layer is

$$\alpha' = [\alpha^2 + 2 \times 10^{-6} dMdh(h_{i+1} - h_i)]^{1/2} \quad (\text{rad}) \quad (16)$$

and r' is calculated as above. Once the range traveled by the ray to the height of the evaporation duct is known, it is doubled and ray tracing continues with downgoing rays at the radar antenna height (Fig. 1).

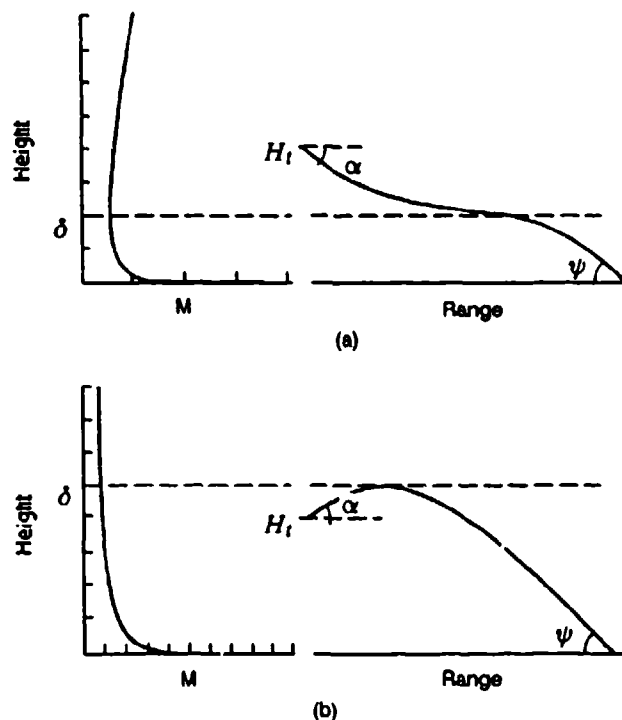


Figure 1. Ray trace for antenna (a) above the evaporation duct height and (b) below the evaporation duct height.

These calculations of the grazing angle do not take into account the effect that a surface-based duct from elevated refractive layers could have on the clutter return for a radar in the duct.

3.2 RADAR CLUTTER CROSS SECTION

Wind speed and direction and average wave height are used to describe the condition of the sea surface. Radar frequency and polarization are system parameters that, along with the grazing angle, describe the effects of the interaction between an electromagnetic wave and the sea surface. Radar wavelength, λ , is

$$\lambda = \frac{300}{f} \quad (\text{m}) \quad (17)$$

where f is frequency in megahertz. Average wavelength of the ocean windwaves, h_{av} , is

$$h_{av} = \left(\frac{V_w}{8.67} \right)^{2.5} \quad (\text{m}) \quad (18)$$

where V_w is wind speed in m/s. Equation 18 assumes a fully risen sea and steady-state conditions. Under transient conditions, V_w and h_{av} are decoupled; the model can be used with these two variables input separately. Three factors need to be calculated. The interference factor is

$$A_i = \frac{\sigma_\phi^4}{1 + \sigma_\phi^4} \quad (19)$$

where

$$\sigma_\phi = \frac{(14.4 \lambda + 5.5)\psi h_{av}}{\lambda} \quad (20)$$

The upwind/downwind factor is

$$A_u = \exp[0.2 \cos(\phi)(1 - 2.8\psi)(\lambda + 0.02)^{-0.4}] \quad (21)$$

where ϕ is the wind direction (degrees) relative to the antenna boresight. The wind speed factor is

$$A_w = \left(\frac{1.9425V_w}{1 + \frac{V_w}{15}} \right)^{q_w} \quad (22)$$

where the exponent $q_w = 1.1 (\lambda + 0.02)^{-0.4}$. Then, the average radar cross section per unit area for horizontal polarization is

$$\sigma_{hh}^0 = 10 \log(3.9 \times 10^{-6} \lambda \psi^{0.4} A_i A_u A_w) \quad (\text{dB}) \quad (23)$$

where the subscript hh indicates horizontal polarization on transmit and receive. (Cross-polarization clutter levels are not considered.) For vertical polarization and frequencies of 3000 MHz and greater

$$\sigma_{vv}^0 = \sigma_{hh}^0 - 1.05 \ln(h_{av} + 0.02) + 1.09 \ln(\lambda) + 1.27 \ln(\psi + 0.0001) + 9.7 \quad (\text{dB}) \quad (24)$$

where \ln is the natural logarithm. For vertical polarization and frequencies less than 3000 MHz

$$\sigma_{vv}^0 = \sigma_{hh}^0 - 1.73 \ln(h_{av} + 0.02) + 3.76 \ln(\lambda) + 2.46 \ln(\psi + 0.0001) + 22.2 \quad (\text{dB}) \quad (25)$$

For circular polarization, σ^0 is equal to the larger of σ_{vv}^0 or σ_{hh}^0 minus 6 dB. The clutter at the maximum range is determined by linear interpolation. If the maximum range exceeds the range for which grazing angles can be calculated, an attenuation rate is applied to the last calculated value of σ^0 at the limiting grazing angle ψ_l . The attenuation rate is adapted from the standard propagation model:⁵

$$\alpha = \{92.516 - [8608.7593 - (\Delta - 20.2663)^2]^{1/2}\} \quad (\text{dB/km}) \quad (26)$$

where Δ is the scaled evaporation duct height, and α is constrained to be no less than 0.0009. The scaled evaporation duct height is

$$\Delta = \delta Z_N \quad (\text{m}) \quad (27)$$

which is constrained to be 23.3 meters or less. The attenuation rate is also scaled by

$$\beta = \alpha R_N \quad (\text{dB/km}) \quad (28)$$

Z_N and R_N are height and range scaling factors found from

$$\begin{aligned} Z_N &= 2.214 \cdot 10^{-3} f^{2/3} \\ R_N &= 4.705 \cdot 10^{-2} f^{1/3} \end{aligned} \quad (29)$$

The normalized radar clutter cross section at the maximum range is then

$$\sigma_{r_{\max}} = \sigma_{\psi_l}^0 - 2 \beta \Delta r \quad (\text{dB}) \quad (30)$$

where Δr is the range difference between r_{\max} and the range of ψ_l . This model for normalized radar clutter cross section does not take ocean swell into account.

The clutter cross section is

$$\sigma_c = \sigma^0 + A_c \quad (\text{dBsm}) \quad (31)$$

where σ^0 is normalized radar cross section of the sea surface and A_c is the area of ocean surface illuminated by the radar:

$$A_c = 10 \log (1890 BW_h \tau_c r) \quad (\text{dBsm}) \quad (32)$$

where BW_h is horizontal beamwidth in degrees, τ_c is compressed pulse length in microseconds, and r is range in kilometers. If the radar does not use pulse compression techniques, then the normal pulse length in microseconds is used in determining the area of the radar resolution cell.

4.0 TEST CASES FOR CALCULATION OF AVERAGE SEA CLUTTER

This section lists input data and output data to verify the proper implementation of the computer program listed in the appendix. Intermediate results are also included to aid in isolating errors. Table 3 lists the input data for the first test case. This test case is typical of clutter under standard propagation conditions for an X-band radar system. Table 4 shows intermediate calculations of elevation angle, grazing angle at the surface, normalized radar sea clutter, and radar resolution cell versus range. Table 5 shows the final results of sea clutter versus range. If the program is properly implemented, the final results should agree within ± 1 in the least significant digit.

Table 3. Input data for Test Case 1.

Input		Description
5.0		! surface wind speed in m/s
0.0		! wind dir. rel. to boresight (deg)
0.0		! evap duct ht in m
4		! # of levels in profile
0.0	350.0	! ht. & <i>M</i> arrays in m & <i>M</i>
10.0	351.0	
1000.0	468.0	
5000.0	940.0	
30.0		! radar antenna ht (m)
9000.0		! radar freq (MHz)
H		! antenna polarization
2.5		! hor. beam width (deg)
1.0		! compressed pulse length (μ s)
50.0		! max range (km)

Table 4. Intermediate results for Test Case 1.

Range, r (km)	Elevation Angle, α (rad)	Grazing Angle, ψ (rad)	Normalized Radar Sea Clutter, σ^0 (dB)	Radar Resolution Cell, A_c (dBsm)	Radar Sea Clutter, σ_c (dBsm)
0.17452	-0.17193	0.17191	-39.82479	29.16253	-10.66226
0.23234	-0.12912	0.12909	-39.98860	30.40524	-9.58336
0.34773	-0.08630	0.08626	-40.36736	32.15649	-8.21087
0.38600	-0.07774	0.07769	-40.49141	32.60989	-7.88152
0.43380	-0.06918	0.06912	-40.64383	33.11694	-7.52689
0.49523	-0.06061	0.06055	-40.83755	33.69205	-7.14550
0.57673	-0.05205	0.05198	-41.09835	34.35378	-6.74457
0.69049	-0.04349	0.04340	-41.48647	35.13559	-6.35088
0.86033	-0.03492	0.03482	-42.17085	36.09069	-6.08016
1.14118	-0.02636	0.02622	-43.71303	37.31754	-6.39549
1.69574	-0.01780	0.01759	-47.98866	39.03761	-8.95105
1.78255	-0.01694	0.01672	-48.71342	39.25444	-9.45898
1.87883	-0.01608	0.01585	-49.51404	39.48289	-10.03115
1.98618	-0.01523	0.01498	-50.39718	39.72420	-10.67298
2.10665	-0.01437	0.01411	-51.37030	39.97995	-11.39035
2.24286	-0.01352	0.01324	-52.44196	40.25204	-12.18991
2.39813	-0.01266	0.01236	-53.62233	40.54275	-13.07958
2.57681	-0.01180	0.01148	-54.92403	40.85485	-14.06919
2.78473	-0.01095	0.01060	-56.36315	41.19185	-15.17130
3.02988	-0.01009	0.00971	-57.96095	41.55827	-16.40268
3.32345	-0.00923	0.00882	-59.74651	41.95991	-17.78660
3.68186	-0.00838	0.00792	-61.76105	42.40469	-19.35636
4.13012	-0.00752	0.00701	-64.06571	42.90364	-21.16207
4.70864	-0.00667	0.00608	-66.75675	43.47298	-23.28378
5.48822	-0.00581	0.00512	-69.99928	44.13834	-25.86095
6.60798	-0.00495	0.00413	-74.11634	44.94470	-29.17164
8.39934	-0.00410	0.00305	-79.90308	45.98647	-33.91661
12.06655	-0.00324	0.00173	-90.68350	47.55985	-43.12365

Table 5. Final values for Test Case 1.

Range, r (km)	Average Radar Sea Clutter, σ_c (dBsm)
0.17	-10.66
0.23	-9.58
0.35	-8.21
0.39	-7.88
0.43	-7.53
0.50	-7.15
0.58	-6.74
0.69	-6.35
0.86	-6.08
1.14	-6.40
1.70	-8.95
1.78	-9.46
1.88	-10.03
1.99	-10.67
2.11	-11.39
2.24	-12.19
2.40	-13.08
2.58	-14.07
2.78	-15.17
3.03	-16.40
3.32	-17.79
3.68	-19.36
4.13	-21.16
4.71	-23.28
5.49	-25.86
6.61	-29.17
8.40	-33.92
12.07	-43.12
50.00	-183.45

Table 6 lists the input data for Test Case 2. This test case varies from Test Case 1 in that the relative wind is a crosswind and the propagation conditions are that of a 13-meter evaporation duct. Table 7 shows intermediate calculations of elevation angle, grazing angle at the surface, normalized radar sea clutter, and radar resolution cell versus range. Table 8 shows the final results of sea clutter versus range. If the program is properly implemented, the final results should agree within ± 1 in the least significant digit.

Table 6. Input data for Test Case 2.

Input		Description
5.0		surface wind speed in m/s
90.0		wind dir. rel. to boresight (deg)
13.0		evap duct ht in m
4		# of levels in profile
0.0	350.0	ht. & <i>M</i> arrays in m & <i>M</i>
10.0	351.0	
1000.0	468.0	
5000.0	940.0	
30.0		radar antenna ht (m)
9000.0		radar freq (MHz)
H		antenna polarization
2.5		hor. beam width (deg)
1.0		compressed pulse length (μ s)
50.0		max range (km)

Table 7. Intermediate results for Test Case 2.

Range, r (km)	Elevation Angle, α (rad)	Grazing Angle, ψ (rad)	Normalized Radar Sea Clutter, σ^0 (dB)	Radar Resolution Cell, A_c (dBsm)	Radar Sea Clutter, σ_c (dBsm)
0.17330	-0.17277	0.17286	-41.27011	29.13188	-12.13823
0.23212	-0.12949	0.12961	-41.77278	30.40117	-11.37162
0.34837	-0.08621	0.08639	-42.49220	32.16438	-10.32782
0.38675	-0.07755	0.07776	-42.68478	32.61832	-10.06646
0.43536	-0.06890	0.06913	-42.90594	33.13248	-9.77346
0.49805	-0.06024	0.06050	-43.16871	33.71676	-9.45195
0.58163	-0.05158	0.05189	-43.49904	34.39051	-9.10853
0.69889	-0.04293	0.04330	-43.95747	35.18808	-8.76938
0.87557	-0.03427	0.03473	-44.71241	36.16693	-8.54547
1.17170	-0.02562	0.02623	-46.30869	37.43217	-8.87651
1.77088	-0.01696	0.01787	-50.42794	39.22591	-11.20202
1.86633	-0.01610	0.01705	-51.09497	39.45390	-11.64107
1.97272	-0.01523	0.01624	-51.82214	39.69468	-12.12746
2.09198	-0.01436	0.01543	-52.61243	39.94959	-12.66284
2.22664	-0.01350	0.01463	-53.46852	40.22051	-13.24801
2.37983	-0.01263	0.01383	-54.39278	40.50948	-13.88329
2.55577	-0.01177	0.01305	-55.38715	40.81924	-14.56791
2.75992	-0.01090	0.01227	-56.45305	41.15298	-15.30007
2.99960	-0.01004	0.01151	-57.59114	41.51465	-16.07649
3.28506	-0.00917	0.01077	-58.80091	41.90945	-16.89146
3.63102	-0.00831	0.01004	-60.08001	42.34431	-17.73570
4.05901	-0.00744	0.00934	-61.42309	42.82822	-18.59487
4.60268	-0.00657	0.00866	-62.82013	43.37412	-19.44600
5.31701	-0.00571	0.00802	-64.25374	44.00069	-20.25305
6.29973	-0.00484	0.00743	-65.69566	44.73724	-20.95842
7.74440	-0.00398	0.00690	-67.10223	45.63390	-21.46833
10.10779	-0.00311	0.00644	-68.41035	46.79058	-21.61978
14.89990	-0.00225	0.00607	-69.53645	48.47585	-21.06060
52.84929	-0.00138	0.00581	-70.38317	53.97441	-16.40876

Table 8. Final values for Test Case 2.

Range, r (km)	Average Radar Sea Clutter, σ_c (dBsm)
0.17	-12.14
0.23	-11.37
0.35	-10.33
0.39	-10.07
0.44	-9.77
0.50	-9.45
0.58	-9.11
0.70	-8.77
0.88	-8.55
1.17	-8.88
1.77	-11.20
1.87	-11.64
1.97	-12.13
2.09	-12.66
2.23	-13.25
2.38	-13.88
2.56	-14.57
2.76	-15.30
3.00	-16.08
3.29	-16.89
3.63	-17.74
4.06	-18.59
4.60	-19.45
5.32	-20.25
6.30	-20.96
7.74	-21.47
10.11	-21.62
14.90	-21.06
50.00	-16.76

Table 9 lists the input data for Test Case 3. Test Case 3 verifies the proper operation of the program at a lower frequency under propagation conditions defined by an effective earth radius factor of 1.2 ($dM/dz = 0.13$ M/m). Table 10 shows intermediate calculations of elevation angle, grazing angle at the surface, normalized radar sea clutter, and radar resolution cell versus range. Table 11 shows the final results of sea clutter versus range. If the program is properly implemented, the final results should agree within ± 1 in the least significant digit.

Table 9. Input data for Test Case 3.

Input	Description
5.0	I surface wind speed in m/s
0.0	I wind dir. rel. to boresight (deg)
0.0	I evap duct ht in m
3	I # of levels in profile
0.0 350.0	I ht. & M arrays in m & M
10.0 480.0	
1000.0 1000.0	
5000.0	
30.0	I radar antenna ht (m)
1000.0	I radar freq (MHz)
H	I antenna polarization
2.4	I hor. beam width (deg)
1.0	I compressed pulse length (μ s)
50.0	I max range (km)

Table 10. Intermediate results for Test Case 3.

Range, r (km)	Elevation Angle, α (rad)	Grazing Angle, ψ (rad)	Normalized Radar Sea Clutter, σ^0 (dB)	Radar Resolution Cell, A_c (dBsm)	Radar Sea Clutter, σ_c (dBsm)
0.17188	-0.17453	0.17453	-47.58787	28.91886	-18.66901
0.43307	-0.06925	0.06925	-58.02119	32.93227	-25.08892
0.69426	-0.04317	0.04317	-66.57854	34.98193	-31.59661
0.95545	-0.03134	0.03134	-72.60278	36.36879	-36.23398
1.21664	-0.02458	0.02458	-77.20615	37.41834	-39.78781
1.47783	-0.02020	0.02020	-80.93079	38.26297	-42.66782
1.73902	-0.01714	0.01714	-84.06212	38.96977	-45.09235
2.00021	-0.01487	0.01487	-86.76709	39.57748	-47.18961
2.26140	-0.01312	0.01312	-89.15154	40.11050	-49.04104
2.52259	-0.01173	0.01173	-91.28673	40.58520	-50.70153
2.78378	-0.01060	0.01060	-93.22287	41.01308	-52.20979
3.04497	-0.00966	0.00966	-94.99673	41.40256	-53.59417
3.30616	-0.00886	0.00886	-96.63602	41.75997	-54.87605
3.56735	-0.00818	0.00818	-98.16217	42.09019	-56.07198
3.82854	-0.00759	0.00759	-99.59206	42.39706	-57.19499
4.08973	-0.00707	0.00707	-100.93926	42.68368	-58.25558
4.35092	-0.00661	0.00661	-102.21488	42.95255	-59.26234
4.61211	-0.00621	0.00621	-103.42805	43.20573	-60.22232
4.87330	-0.00584	0.00584	-104.58645	43.44497	-61.14148
5.13449	-0.00551	0.00551	-105.69657	43.67171	-62.02486
5.39568	-0.00521	0.00521	-106.76396	43.88720	-62.87677
5.65688	-0.00494	0.00494	-107.79343	44.09249	-63.70094
5.91807	-0.00469	0.00469	-108.78914	44.28853	-64.50061
6.17926	-0.00446	0.00446	-109.75471	44.47609	-65.27863
6.44045	-0.00424	0.00424	-110.69342	44.65589	-66.03753
6.70164	-0.00404	0.00404	-111.60809	44.82854	-66.77954
6.96283	-0.00386	0.00386	-112.50133	44.99459	-67.50674
7.22402	-0.00369	0.00369	-113.37543	45.15452	-68.22092
7.48521	-0.00352	0.00352	-114.23251	45.30877	-68.92374
7.74640	-0.00337	0.00337	-115.07449	45.45773	-69.61676
8.00759	-0.00323	0.00323	-115.90313	45.60175	-70.30138
8.26878	-0.00309	0.00309	-116.72008	45.74115	-70.97893
8.52997	-0.00297	0.00297	-117.52682	45.87621	-71.65061
8.79116	-0.00284	0.00284	-118.32481	46.00719	-72.31762
9.05235	-0.00273	0.00273	-119.11538	46.13435	-72.98103
9.31354	-0.00262	0.00262	-119.89980	46.25788	-73.64191
9.57473	-0.00251	0.00251	-120.67928	46.37800	-74.30128
9.83592	-0.00241	0.00241	-121.45501	46.49488	-74.96013
10.09711	-0.00232	0.00232	-122.22810	46.60870	-75.61940
10.35830	-0.00223	0.00223	-122.99966	46.71962	-76.28004
10.61950	-0.00214	0.00214	-123.77080	46.82777	-76.94302
10.88069	-0.00205	0.00205	-124.54256	46.93330	-77.60926
11.14188	-0.00197	0.00197	-125.31601	47.03632	-78.27969
11.40307	-0.00189	0.00189	-126.09224	47.13695	-78.95529
11.92545	-0.00175	0.00175	-127.65739	47.33148	-80.32591

Table 11. Final values for Test Case 3.

Range, r (km)	Average Radar Sea Clutter, σ_c (dBsm)
0.17	-18.67
0.43	-25.09
0.69	-31.60
0.96	-36.23
1.22	-39.79
1.48	-42.67
1.74	-45.09
2.00	-47.19
2.26	-49.04
2.52	-50.70
2.78	-52.21
3.04	-53.59
3.31	-54.88
3.57	-56.07
3.83	-57.19
4.09	-58.26
4.35	-59.26
4.61	-60.22
4.87	-61.14
5.13	-62.02
5.40	-62.88
5.66	-63.70
5.92	-64.50
6.18	-65.28
6.44	-66.04
6.70	-66.78
6.96	-67.51
7.22	-68.22
7.49	-68.92
7.75	-69.62
8.01	-70.30
8.27	-70.98
8.53	-71.65
8.79	-72.32
9.05	-72.98
9.31	-73.64
9.57	-74.30
9.84	-74.96
10.10	-75.62
10.36	-76.28
10.62	-76.94
10.88	-77.61
11.14	-78.28
11.40	-78.96
11.93	-80.33
50.00	-144.79

Table 12 lists the input data for Test Case 4. Test Case 4 tests the program for a higher antenna height, vertical polarization, a wider horizontal beam, and a longer compressed pulse. Because of the

higher antenna, the maximum range has been set to 200 km. Table 13 shows intermediate calculations of elevation angle, grazing angle at the surface, normalized radar sea clutter, and radar resolution cell versus range. Table 14 shows the final results of sea clutter versus range. If the program is properly implemented, the final results should agree within ± 1 in the least significant digit.

Table 12. Input data for Test Case 4.

Input	Description
5.0	l surface wind speed in m/s
0.0	l wind dir. rel. to boresight (deg)
0.0	l evap duct ht in m
4	l # of levels in profile
0.0 350.0	l ht. & M arrays in m & M
10.0 351.0	
1000.0 468.0	
5000.0 940.0	
1000.0	l radar antenna ht (m)
9000.0	l radar freq (MHz)
V	l antenna polarization
5.0	l hor. beam width (deg)
2.5	l compressed pulse length (μ s)
200.0	l max range (km)

Table 13. Intermediate results for Test Case 4.

Range, r (km)	Elevation Angle, α (rad)	Grazing Angle, ψ (rad)	Normalized Radar Sea Clutter, σ^0 (dB)	Radar Resolution Cell, A_c (dBsm)	Radar Sea Clutter, σ_c (dBsm)
6.01684	-0.16655	0.16584	-34.76330	50.55821	15.79501
7.91571	-0.12680	0.12586	-35.28127	51.74952	16.46825
11.57980	-0.08704	0.08567	-36.13678	53.40163	17.26485
12.76520	-0.07909	0.07758	-36.38067	53.82490	17.44423
14.22467	-0.07114	0.06946	-36.66499	54.29504	17.63005
16.06660	-0.06319	0.06129	-37.00522	54.82386	17.81864
18.46782	-0.05524	0.05305	-37.42987	55.42878	17.99891
21.73692	-0.04729	0.04471	-38.00035	56.13660	18.13626
26.47287	-0.03934	0.03620	-38.87930	56.99263	18.11333
34.04010	-0.03139	0.02736	-40.62358	58.08453	17.46095
48.62500	-0.02344	0.01768	-45.67751	59.63322	13.95571
50.93113	-0.02264	0.01661	-46.65054	59.83446	13.18392
53.51353	-0.02184	0.01551	-47.77897	60.04926	12.27029
56.43565	-0.02105	0.01436	-49.09777	60.28016	11.18238
59.78544	-0.02025	0.01317	-50.65598	60.53058	9.87460
63.69080	-0.01946	0.01191	-52.52724	60.80539	8.27815
68.34922	-0.01866	0.01056	-54.83195	61.11196	6.28001
74.09347	-0.01787	0.00909	-57.79104	61.46242	3.67138
81.56604	-0.01707	0.00740	-61.88675	61.87971	-0.00704
92.36490	-0.01628	0.00532	-68.56870	62.41969	-6.14901
115.43026	-0.01548	0.00173	-91.32991	63.38782	-27.94209

Table 14. Final values for Test Case 4.

Range, r (km)	Average Radar Sea Clutter, σ_c (dBsm)
6.0	15.8
7.9	16.5
11.6	17.3
12.8	17.4
14.2	17.6
16.1	17.8
18.5	18.0
21.7	18.1
26.5	18.1
34.0	17.5
48.6	14.0
50.9	13.2
53.5	12.3
56.4	11.2
59.8	9.9
63.7	8.3
68.4	6.3
74.1	3.7
81.6	0.0
92.4	-6.2
115.4	-27.9
200.0	-352.2

5.0 REFERENCES

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4. Patterson, W. L., et al., "Engineer's Refractive Effects Prediction System (EREPS) Revision 2.0," Naval Ocean Systems Center TD 1342 Revision 2.0, February 1990.
5. Hattan, C. P., "Specification for a Standard Electromagnetic Propagation Model," Naval Ocean Systems Center TD 1772, June 1990.


```

c     effective earth radius effects are assumed to dominate the
c     determination of grazing angle.
c
IF (freq .GE. 2000.) THEN
    CALL psir(delta, Ht, alpha, psi, r, imax)
ELSE
    CALL mprof (height, Munits, Ht, levels, ALPHAC, DMDH, HMRS,
2         SBDHT, NTOT)
    CALL getk (alphac, dmdh, hmrs, ntot, Ht, RK)
    CALL psirae (rk, Ht, rmax, alpha, psi, r, imax)
END IF

c
c     invert r, psi, and alpha arrays so range increases with
index
c
    limit= IFIX(FLOAT(imax)/2.)
DO i=1, limit
    rng = r(i)
    angle = alpha(i)
    angl = psi(i)
    r(i) = r(imax+1-i)
    psi(i) = psi(imax+1-i)
    alpha(i) = alpha(imax+1-i)
    r(imax+1-i) = rng
    psi(imax+1-i) = angl
    alpha(imax+1-i) = angle
END DO

c
c     determine reflectivity from grazing angle
c
DO i = 1, imax
    CALL nracs (Vw, phi, freq, polar, psi(i), sigma0(i))
END DO

c
c     calculate average clutter cross section from normalized
c     reflectivity and clutter resolution cell size
c
acs = 10.*ALOG10(1890.*hbw*cpl)
DO i = 1, imax
    ac = acs + 10.*ALOG10(r(i))
    sigmac(i) = sigma0(i) + ac
    write (6, '(6f12.5)') r(i), alpha(i), psi(i), sigma0(i), ac,
2         sigmac(i)
END DO

c
c     beyond minimum grazing angle, apply an attenuation rate
c     to the reflectivity
c
IF (r(imax) .LT. rmax) THEN
    reflim = sigma0(imax)

```


END

```
c
c Subroutine ducts
c
c DUCTS builds an array containing the top, bottom, and
c minimum refractivity of all the major ducts in the
c atmosphere refractivity profile.
c
c Variable:      Description:
c   dct          3,* duct parameters array.
c                1,n bottom of duct 'n', meters.
c                2,n top of duct 'n', meters.
c                3,n minimum refractivity of duct 'n', M-units.
c   lvls         Number of refractivity level in rmu, rhts.
c   ndcts        in: the maximum number of ducts allowed.
c                out: the number of ducts found.
c   nq           Duct counter.
c   rht          Height array, meters.
c   rmu          Modified refractivity, M-unit array, elements
c                correspond to like-number elements of rht array.
```

```
c
c SUBROUTINE ducts(rmu,rht,lvls,DCT,NDCTS)
c
c   real*4 dct,delu,delh,deltu,hbot,htop,rht(32),rmu(32)
c   integer*2 lvls,ibot,iduct,iend,iq,itop,ndcts,nq
c   dimension dct(3,8)
c
c   Locate all major ducts
c   nq=0
c   iq=3*ndcts
c   itop=lvls
c   iend=ndcts
c   ndcts=0
c   DO iduct=1,iend
c
c       Look for top of next duct
c 1010 continue
c       htop=rht(itop)
c       if(itop.eq.1) go to 1060
c       ibot=itop-1
c       if(rmu(itop).le.rmu(ibot)) go to 1020
c       itop=itop-1
c       go to 1010
c
c       Look for bottom of the duct
c 1020 continue
c       hbot=rht(ibot)
c       if(rmu(ibot).lt.rmu(itop)) go to 1030
c       if(ibot.eq.1) go to 1040
```

```

        ibot=ibot-1
        go to 1020
c
c      Calculate bottom of duct using linear interpolation
1030  continue
        delu=rmu(ibot+1)-rmu(ibot)
        delh=rht(ibot+1)-rht(ibot)
        deltu=rmu(itop)-rmu(ibot)
        if(delu.lt.0.01) go to 1040
        hbot=rht(ibot) + deltu*delh/delu
c
c      Store duct parameters in array dct
1040  continue
        amu=rmu(itop)
        call push(dct,iq,nq,amu)
        call push(dct,iq,nq,htop)
        call push(dct,iq,nq,hbot)
        ndcts=iduct
        itop=ibot
        END DO
c
1060  continue
        RETURN
        END
c
c  Subroutine getk
c
c  Subroutine GETK is used to determine the effective earth radius
c  factor k. Getk accomplishes this by tracing a ray from the trans-
c  mitter height to 200 NMi (370 km). The ray launch angle is 0 deg.
c  if no surface-based duct exists, or alphac, the critical angle if
c  one does.
c
c  Variable:      Description:
c  alphac        Critical angle necessary to escape duct. If alphac
c                = 0 then no surface-based duct exists.
c  a0            Initial ray launch angle, radians.
c  a1            Ray angle at top of layer, radians.
c  deld          Range difference, km.
c  delh          Height difference, meters.
c  delM          M-unit difference.
c  delmdh        M-unit gradient.
c  dMdh          M-unit gradient array.
c  hlast         Height at 370 km.
c  hms          Array of height elements, in meters.
c  ntot         Maximum number of elements in hms and dMdh arrays.
c  rdeld        Range incremented in ray trace.
c  rmax         Maximum range for ray trace - 370 km.
c  rng          Range, km.
c  rk           Effective earth radius factor.

```

```

c   xmtr      Transmitter height in meters.
c
c   SUBROUTINE getk(alphac, dMdh, hms, ntot, xmtr, RK)
c
c   real*4 alphac, a0, a1, deld, delh, delM, delmdh, dMdh(32)
c   real*4 hlast, hms(32), rdeld, rmax, rng, rk, xmtr
c   integer*2 ntot, i
c
c   rmax = 370.0
c   h = xmtr
c   rng = 0.0
c   a0 = alphac
c   Loop to trace ray through the atmospheric layers.
c   DO i=2,ntot-1
c     delm = (hms(i+1) - h)*dMdh(i)*1.0E-3
c     a1 = SQRT(a0*a0 + 2.0*delm)
c     deld = (a1 - a0)/dMdh(i)
c     rdeld = rng + deld
c     IF(rdeld .GT. rmax) GOTO 1000
c     a0 = a1
c     h = hms(i+1)
c     rng = rdeld
c   END DO
c   i = ntot
c 1000 continue
c   Ray trace in final layer to range rmax.
c   deld = rmax - rng
c   a1 = a0 + dMdh(i) * deld
c   delM = (a1*a1 - a0*a0)*0.5
c   delh = 1000.0*delM/dMdh(i)
c   hlast = hms(i) + delh
c   Determine the equivalent single-gradient atmosphere that
c   would be required to trace a ray launched at alphac that
c   would arrive at height = hlast at a range of 370 km.
c   delmdh = (-alphac)*2.0/rmax + 2.0E-3*(hlast - xmtr)/(rmax*rmax)
c   rk = 1.0/(6371.0 * delmdh)
c   IF(rk .GT. 5.0) rk = 5.0
c   IF(rk .LE. 0.5) rk = 0.50
c   RETURN
c   END
c
c Subroutine insrt
c
c
c INSRT inserts (or appends) a new level into the M-unit profile. It
c does this by locating the new height relative to the existing pro-
c file heights. If the new height is greater than the top level, then
c append a new level for the new height. If the new height is between
c two levels, then insert a new level for the new height. If the new
c height is equal to an existing level's height, do not add a new

```

```

c level for the new height.
c
c Variable:      Description:
c   amu          Modified refractivity array, M-units.
c   hms          Height array, meters, each element corresponding to
c                 the like-number amu array element.
c   iq           Number of levels in amu and hms.
c   hgt          Height of new level to be added, meters.
c   ipnt         Index pointer to new level.
c
c
c   SUBROUTINE insrt(amu,hms,iq,hgt,ipnt)
c
c   real*4 amu(32),hms(32),hgt
c   integer*2 iq,ipnt
c
c   DO i=1,iq
c     ilevel=i
c     IF(ABS(hgt-hms(ilevel)).LE.0.01) go to 1020
c     IF(hms(ilevel).GT.hgt) go to 1030
c   END DO
c
c     Hgt > amu(iq)
c     iq=iq+1
c     ipnt=iq
c     grdnt=0.1181102
c     amu(ipnt)=amu(iq-1) + (hgt-hms(iq-1))*grdnt
c     hms(ipnt)=hgt
c     go to 1050
c
c     Hgt = hms(ilevel)
c   1020 continue
c     ipnt=ilevel
c     amu(ipnt)=amu(ilevel)
c     hms(ipnt)=hgt
c     go to 1050
c
c     Hms(ilevel) > hgt > hms(ilevel-1)
c   1030 continue
c     Shift levels above new height up one
c     DO i=ilevel,iq
c       j=iq - (i-ilevel)
c       hms(j+1)=hms(j)
c       amu(j+1)=amu(j)
c     END DO
c     iq=iq+1
c     ipnt=ilevel
c     grdnt=(amu(ipnt+1)-amu(ipnt-1))/(hms(ipnt+1)-hms(ipnt-1))
c     amu(ipnt)=amu(ipnt-1) + (hgt-hms(ipnt-1))*grdnt
c     hms(ipnt)=hgt

```

c go to 1050

c

1050 continue

RETURN

END

c

c Subroutine mprof

c

c MPROF modifies the M-unit and height arrays by inserting a level at
c the antenna height using straight line interpolation (or a standard
c atmosphere gradient) to calculate its M-unit value. The new profile
c is then used to locate any ducts that might be contained in the pro-
c file. If the bottom of the duct is below the EM system antenna
c height, and the top above the antenna height, then a critical angle
c is calculated for the EM system in the surface-based duct. (It is
c assumed that low-elevated ducts are surface ducts if the EM system
is
c in the duct.)

c

c Variable: Description:
c alphac The critical penetration angle necessary to escape
duct

c amu An array of M-unit values
c antena EM system antenna height
c antmu M-unit value at the EM system antenna height
c dcts 24 duct parameter array
c 1,n bottom of duct 'n', meters
c 2,n top of duct 'n', meters
c 3,n minimum refractivity of duct 'n', m-units
c dMdh M-unit gradient array
c hbot Height of the bottom of a duct
c htop Height of the top of a duct
c height Height array with the original profile heights
c hmrs Height array with elements corresponding to the dMdh
c array elements
c lvlant EM system antenna level
c lvltop Maximum number of layers in the hmrs array
c Munits M-unit array with elements corresponding to the height
c array elements
c ndcts The number of ducts stored in 'dcts'
c nmax The number of elements in the height and Munit arrays
c ntot The number of elements in the dMdh and hmrs arrays
c rma M-unit value at the minimum on the duct profile
c sbdht The height of the surface-based duct

c

c Variables not listed are temporary variables.

c

c

SUBROUTINE mprof(height,Munits,antena,nmax,ALPHAC,DMDH,HMRS,
1 SBDHT,NTOT)

```

c
c
real*4 alphac,amu(32),antena,dmdh(32),hmrs(32),height(30)
real*4 Munits(30),sbdht
real*4 antmu,dcts,hb,ht,rma
integer*2 lvlant,lvltop,nmax,ntot
integer*2 ndcts
dimension dcts(3,8)

c
lvltop = nmax
alphac = 0.0
sbdht = 0.0

c
c      Copy height and m-unit arrays.
c
lvltop = nmax
DO i = 1, nmax
  hmrs(i)=height(i)
  amu(i)=Munits(i)
END DO

c
c      Insert new level at the antenna height.
c
call insrt(amu,hmrs,lvltop,antena,lvlant)
antmu=amu(lvlant)

c
c      Locate all major ducts.
ndcts=8
call ducts(amu,hmrs,lvltop,dcts,ndcts)

c
c      Define trapping duct parameters.
IF(ndcts .NE. 0)THEN
  DO iduct=1,ndcts
    hb=dcts(1,iduct)
    ht=dcts(2,iduct)
    rma=dcts(3,iduct)
    IF((antena .GT. hb) .AND. (antena .LT. ht)) go to 1040
    IF(hb.lt.0.01) go to 1040
  END DO
END IF

c
c      Antenna not inside a major duct.
go to 1050

c
c      The antenna is inside a low-level elevated duct
c      or inside a surface-based duct.
1040  continue
      sbdht = ht
      alphac=1.0e-3*sqrt(2.0*(antmu-rma)) + 1.0e-5
1050  continue

```



```

c
c   This subroutine generates arrays of ray launch angle, alpha,
c   grazing angle, psi, and range, r, to be used as inputs to the
c   clutter level calculations.
c
c   Inputs:
c
c       delta, hxmtr
c
c   Outputs:
c
c       alpha(*), angle, idelta, imax, ixmtr, nmax1, psi(*), r(*),
c       rh1(*), rml(*)
c
c   Calling routines:
c
c       clutr
c
c   Routines called:
c
c       ALOG, downgo, EXP, FLOAT, SQRT, upgo
c
c   Glossary:
c
c       alpha(*) - ray launch angle at the transmitter (radians)
c       angle    - ray launch angle at the transmitter (radians)
c       delta    - evaporation duct height (m)
c       hxmtr    - height of the transmitter (m)
c       idelta   - index of level in profile for delta
c       ixmtr    - index of level in profile for hxmtr
c       imax     - number of elements in alpha, psi and r arrays
c       nmax1    - number of elements in generated height and M arrays
c                 (includes radar height and evap duct profile)
c       psi(*)  - grazing angle at the sea surface (radians)
c       rh1(*)  - augmented height array (m)
c       rml(*)  - augmented modified refractivity array (M)
c       r       - range (km)
c
c   Method:
c
c       This subroutine takes the evaporation duct height
c       and radar antenna height, and, using ray trace techniques,
c       returns grazing angle, psi (radians), as a function of range,
c       r (m). Psi is determined directly, by Snell's law, given the
c       radar antenna height, depression (or elevation) angle at the
c       radar, the M-value at that height, and the M-value at the
c       surface. The range is determined by using small angle
c       approximations, a linearly segmented M-profile, and analytic
c       expressions for the ray path in each segment. The evaporation
c       duct profile is assumed to be for neutral conditions and uses

```

```

c      the Jeske formulation. The evaporation duct profile is
c      extended to the radar antenna height, if necessary, by
c      extrapolating with a gradient of 118 M/km.
c
c
c
c
cccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccc
c
c
c
c
SUBROUTINE psir (delta, hxmtr, alpha, psi, r, imax)
c
DIMENSION rh1(10), rml(10)
DIMENSION alpha(50), psi(50), r(50)
c
COMMON /RAYTRACE/ rh1, rml
c
z0 = 0.00015      ! surface roughness parameter (m)
z1 = 6.           ! reference height (m)
k = 0.4          ! von Karmen's constant
c
      calculate M-profile for input delta, neutral stability
c
rmsfc = 340.0
rh1(1) = 0.
rml(1) = rmsfc
DO i = 2, 8      ! logarithmic
height
      rlz = FLOAT(i-4)
              z = EXP(rlz)      ! z=
0.135,0.368,1.0,2.7,7.4,20.1,54.6
      rh1(i) = z
      rml(i) = rmsfc + 0.125*z - 0.125 * Delta * ALOG(z/z0)
END DO
nmax1 = 8
c
c      insert delta into M-profile
c
i = 1
DO WHILE (rh1(i) .LT. Delta)
      i = i + 1
END DO
n1 = i
IF (delta .NE. rh1(i)) THEN
      nmax1 = nmax1 + 1
      DO i = nmax1,n1+1,-1
              rh1(i) = rh1(i - 1)
              rml(i) = rml(i - 1)
      END DO
      rh1(n1) = delta
      rml(n1) = rmsfc + 0.125*delta - 0.125*delta*ALOG(delta/z0)

```

```

END IF
idelta = n1
rmmin = rml(n1)
c
c           insert xmtr level into H1 & M1 arrays
c
IF (hxmtr .GT. rh1(nmax1)) THEN
nmax1 = nmax1 + 1
n1 = nmax1
rh1(nmax1) = hxmtr
rml(nmax1) = 0.118*(rh1(nmax1)-rh1(nmax1-1)) + rml(nmax1-1)
rmxmtr = rml(nmax1)
ELSEIF (hxmtr .EQ. rh1(nmax1)) THEN
rmxmtr = rml(nmax1)
n1 = nmax1
ELSE
i = 2
DO WHILE (rh1(i) .LT. hxmtr)
i = i + 1
END DO
n1 = i
IF (hxmtr .EQ. rh1(i)) THEN
rmxmtr = rml(i)
ELSE
grad = (rml(i)-rml(i-1)) / (rh1(i) - rh1(i-1))
rmxmtr = rml(i-1) + (hxmtr-rh1(i-1))*grad
nmax1 = nmax1 + 1
DO i = nmax1, n1+1, -1
rh1(i) = rh1(i-1)
rml(i) = rml(i-1)
END DO
rh1(n1) = hxmtr
rml(n1) = rmxmtr
END IF
END IF
ixmtr = n1
IF (hxmtr .LT. delta) idelta = idelta + 1
c
c           Determine psi for -10 < alpha < alphmx deg.
c           Alpha is the launch angle at the radar; alphmx is
c           the angle that yields the longest range to the surface;
c           Alphmn is max depression angle - giving a max grazing
c           angle at the surface of approx. 10 deg.
c
alphmn = -0.1745
radcnd = 0.000002*(rmxmtr-rmmin)
IF (radcnd .LE. 0.) THEN
alphmx = -0.000001
ELSE
alphmx = -SQRT(radcnd) - 0.000001

```



```

DIMENSION alpha(50), psi(50), r(50)
c
ae = rk * 6371.
c
c       determine the range at which psi= .1 deg
c
psi(1) = 0.001745
a = 1.
b = 2. * ae * psi(1)
c = -2. * ae * hxmtr / 1000.
r(1) = (-b + SQRT(b*b - 4.*a*c)) / (2.*a)
IF (r(1) .GT. rmax) r(1) = rmax
alpha(1) = -(hxmtr/(1000.*r(1)) - r(1)/(2.*ae))
c
c       determine range at which psi = 10 deg
c
b = 2. * ae * 0.1745
rmin = (-b + SQRT(b*b - 4.*a*c)) / (2.*a)
c
c       determine alpha & psi for intermediate ranges
c
i = 1
dr = r(1) - rmin
DO i = 2, 45
  r(i) = r(1) - dr*i/45.
  alpha(i) = -(hxmtr/(1000.*r(i)) - r(i)/(2.*ae))
  psi(i) = hxmtr/(1000.*r(i)) - r(i)/(2.*ae)
END DO
imax = 45
c
c
RETURN
END
c
c Subroutine push
c
c PUSH stores elements in an array and returns.
c
c Variable:      Description:
c
c array          iq array to hold data elements
c iq             Size of data array
c nq             Number of data elements stored in data array
c data           The data element to be stored
c
c
c SUBROUTINE push(ARRAY,iq,nq,data)
c
c real*4 data,array
c integer*2 iq,nq

```


REPORT DOCUMENTATION PAGE

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