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XTRAN: AN ATMOSPHERIC TRANSMITTANCE CODE BASED ON XSCALE

April 1991

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13. ABSTRACT (*Maximum 200 words*)

Several Electro-Optical Systems Atmospheric Effects Library modules require the use of XSCALE for calculation of the natural atmospheric transmittance value. XSCALE is a large (over 1600 lines of code) algorithm, which, in some cases, requires other external modules or data files for execution.

XTRAN, a comparatively smaller (less than 240 lines) computer code, was develcped for use with the KWIK (crosswind integrated concentration) munition expenditure stand-alone versions (SKWIK and IKWIK). XTRAN computes horizontal extinction and transmittance values based on the XSCALE module for visible, near-, mid-, and far-infrared wavelengths by using estimated values of visibility and polynomial regression equations for aerosol extinction as a function of relative humidity. This report shows the usefulness and practicality of the XTRAN code as a horizontal transmittance model.

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1. INTRODUCTION

The KWIK (crosswind integrated concentration) smoke munition expenditures algorithm (Peña, 1987) and other models, such as LOWTRAN (Pierluissi et al., 1987) and TARGAC (Davis, 1987), use the natural aerosol transmittance data from the EOSAEL (Electro-Optical Systems Atmospheric Effects Library) module XSCALE (Duncan et al., 1987) for wavelengths of 0.2 to 12.5 μm.

The XTRAN algorithm has been developed in an effort to minimize the amount of computer code that is required to calculate horizontal atmospheric transmittance values. XTRAN contains about 240 lines of FORTRAN 77 code (about one-eighth the size of XSCALE) and computes horizontal extinction and transmittance values for the following adverse weather conditions.

- Haze/fog maritime (arctic and polar) air mass
- Haze/fog urban air mass
- Haze/fog rural (continental polar) air mass
- Fog one (heavy advection)
- Fog two (moderate advection)
- Rain (drizzle)
- Rain (widespread)
- Rain (thunderstorm)
- Snow (falling or blowing) for relative humidity (RH) less than 95 percent only

XTRAN uses estimated values of visibility coupled with polynomial regression analysis for natural aerosol extinction as a function of RH to calculate the horizontal atmospheric transmission through a smoke cloud. The polynomial regression equations are obtained by using aerosol extinction coefficients from the RHDATA file from XSCALE. The code for fog one, fog two, rain (drizzle, widespread, and thunderstorm), and snow is taken from XSCALE. XTRAN's only limitation is its exclusion of snow at greater than 95 percent RH and ice fog condition.

XTRAN is used in SKWIK (a short version of the EOSAEL KWIK model) and IKWIK (inverse KWIK tactical decision aid). Peña (1991) describes the latest personal computer (PC) versions of EOSAEL KWIK, SKWIK, and IKWIK. This report presents the results of a comparative study of the effects of using XTRAN versus XSCALE transmittance data with the KWIK model.

2. VISIBILITY AND CONTRAST THRESHOLD VALUES

Two terms that are widely used together with "visibility" are visual range and meteorological range. All three terms are often used interchangeably; but according to McCartney (1976), visual range is the more useful quantity because it allows for a target/background contrast of less than unity and/or a threshold contrast of more than 2 percent.
Visual range* is defined as

$$R_v = \frac{1}{K_e} \ln \frac{C}{\epsilon} \qquad (1)$$

*In this report, the term "visibility" will be used interchangeably with visual range.

where K_e is the extinction coefficient in the visual wavelength band, C is the inherent target contrast against a background (considered to be unity where a black target is against the background), and ϵ is the constant threshold value.

During the Smoke Week VII trials, where live-fired smoke munitions were used, LOVIR (low visibility infrared) transmissometry data were compared with corresponding results from the PRESTO (personal evaluation system for target obscuration) system. Peña (1986) showed that these results indicate that the threshold contrast value was approximately 0.10 for visible and near-infrared wavelengths and 0.05 for mid- and far-infrared wavelengths.

Restating equation (1) for visible and near-infrared wavelengths,

$$R_v = \frac{1}{K_e} \ln \frac{1}{0.10} \qquad (2)$$

or

$$K_e = \frac{2.303}{R_v} \qquad (3)$$

For mid- and far-infrared wavelengths the extinction coefficient becomes

$$K_e = \frac{3.00}{R_v} \qquad (4)$$

3. EXTINCTION COEFFICIENTS

Lower atmospheric aerosol particle sizes are a function of air mass as well as RH. These particles, however, grow with increasing RH. The XSCALE module (Duncan et al., 1987) uses Mie theory to calculate atmospheric absorption and extinction coefficients. The results, found in the RHDATA file, are tabulated for eight RH levels (0, 50, 70, 80, 90, 95, 98, and 99 percent) and 31 wavelengths, ranging from 0.2 to 12.5 μm, for each RH level.

Equations (3) and (4) were modified as follows for visible (0.55 μm) and near-infrared (1.06 μm) and for mid- (3.75 μm) and far-infrared (10.6 μm) wavelengths, respectively.

$$K_e = \frac{2.3}{R_v} K_t \qquad (5)$$

$$K_e = \frac{3.00}{R_v} K_t \qquad (6)$$

K_t is the corresponding extinction value from the RHDATA file (see appendix A) for the particular aerosol, wavelength, and RH value.

Regression analysis techniques were applied to the K_e extinction values (see appendix A tables A-1 through A-9) for near-, mid-, and far-infrared wavelengths, six RH values (0, 50, 70, 80, 90, and 95 percent) and four values of visibility (2.3, 10, 20, and 30 km). This technique produced a series of four equations per wavelength band and aerosol type (see appendix C, subroutine XTRAN) of the form

$$Kext = A + B(RH) + C(RH)^2 + D(RH)^3 \ldots \quad (7)$$

Appendix B shows the procedure used to obtain the extinction coefficients for fog one and fog two for 2.3, 10, 20, and 30 km visibility.

Appendix C presents the rain and snow extinction coefficients. Note that the calculations for falling and blowing snow are valid only for RH less than 95 percent.

Appendix D shows the FORTRAN 77 source code for the XTRAN algorithm containing all regression equations and calculations for transmittance.

4. TRANSMITTANCE COMPARATIVE CALCULATIONS: XSCALE VERSUS XTRAN

Comparative calculations of transmittance values using XSCALE and XTRAN were performed on identical meteorological data (line-of-sight visibility, RH, windspeed, temperature, and horizontal slant range) for maritime, urban, and rural aerosol. The visibility values used with XSCALE were 1.5, 10, 15, 20, and 25 km. XTRAN used visibilities of 2.3, 10, 20, and 30 km (see table 1). The XTRAN values of 2.3, 20, and 30 km were used instead of 1.5, 15, and 25 km, in order to determine the sensitivity of visibility estimates used in calculating transmittance values.

Table 1 shows the comparative calculations of maritime, urban, and rural aerosol transmittance values for visible, near-, mid-, and far-infrared wavelengths. Horizontal slant ranges of 1.0 and 2.0 km were used in all three aerosol calculations. The numbers in parentheses for visibility represent the values used by the XTRAN algorithm. In the same manner, the transmittance values calculated by XTRAN are also shown in parentheses. The visible transmittance column in table 1 shows only one set of numbers because there was no difference between the XSCALE and XTRAN calculations for this wavelength.

Since XSCALE uses the threshold contrast value of 0.02 for all wavelengths and XTRAN (and also KWIK) uses 0.10 for visible and near-infrared and 0.05 for mid- and far-infrared wavelengths (as explained above), it was necessary to apply an adjustment factor to the XSCALE transmittance values to make them comparable to the XTRAN calculated values. The following relationships were used.

For visible and near-infrared wavelengths

$$T_{vn} = (T_{xscale})^{0.5887} \quad (8)$$

and for mid- and far-infrared wavelengths

$$T_{mf} = (T_{xscale})^{0.76577} \quad (9)$$

where T_{xscale} is the transmittance value calculated by XSCALE for a particular wavelength. The transmittance values calculated by XTRAN for all wavelengths and air masses were derived from the following general expression

$$T = \exp\left[-(S_{rang}\ K_e)\right] \quad (10)$$

where S_{rang} is the horizontal slant range in kilometers.

TABLE 1. COMPARATIVE TRANSMITTANCE VALUES BETWEEN XSCALE AND XTRAN

Visibility (km)	SRNG (km)	Visible	Near IR	Mid IR	Far IR
		Maritime Aerosol			
1.5 (2.3)*	1.0	.215	.330 (.485)*	.538 (.669)*	.842 (.894)*
10. (10.)	1.0	.794	.846 (.848)	.911 (.908)	.974 (.980)
15. (20.)	2.0	.736	.764 (.825)	.789 (.860)	.940 (.988)
20. (20.)	2.0	.794	.817 (.825)	.837 (.860)	.955 (.988)
25. (30.)	2.0	.832	.850 (.817)	.857 (.864)	.958 (.986)
		Urban Aerosol			
1.5 (2.3)	1.0	.215	.486 (.620)	.756 (.830)	.835 (.894)
10. (10.)	1.0	.794	.897 (.896)	.959 (.959)	.973 (.974)
15. (20.)	2.0	.736	.868 (.894)	.947 (.958)	.968 (.976)
20. (20.)	2.0	.794	.899 (.894)	.960 (.958)	.976 (.976)
25. (30.)	2.0	.832	.917 (.927)	.968 (.972)	.982 (.984)
		Rural Aerosol			
1.5 (2.3)	1.0	.215	.524 (.654)	.819 (.873)	.852 (.897)
10. (10.)	1.0	.794	.908 (.905)	.970 (.967)	.976 (.976)
15. (20.)	2.0	.736	.876 (.901)	.955 (.963)	.970 (.976)
20. (20.)	2.0	.794	.905 (.901)	.966 (.963)	.977 (.976)
25. (30.)	2.0	.823	.922 (.932)	.937 (.974)	.983 (.984)

*NOTE: XTRAN visibility and transmittance values are shown in parentheses.

5. MUNITION EXPENDITURES COMPARATIVE CALCULATIONS: SKWIK VERSUS EOSAEL KWIK

A second comparison test that was run is shown in tables 2, 3, and 4. These tables show the actual and percent difference in munition expenditures of a series of calculations using identical input data for SKWIK and EOSAEL KWIK for maritime, urban, and rural aerosols. The XTRAN subroutine in SKWIK used 2.3, 10, 20, and 30 km approximations for actual visibility, as shown in these tables. The tables also show positive digits to indicate cases where the number of rounds calculated by SKWIK were in excess (overprediction) of the EOSAEL KWIK calculations and negative digits to indicate the cases where SKWIK underpredicted EOSAEL KWIK. A zero was used to indicate no difference between the computed values. The results are also presented, respectively, as plus, minus, or zero percent difference.

The "worst" case produced by these comparative calculations occurred with maritime aerosol (see table 2), where the SKWIK overprediction was between two and seven rounds (5.0 and 5.3 percent). However, 19 cases out of 24 (79 percent) showed no difference. Table 3 (urban aerosol) showed four cases of two-round overprediction and a total average difference of 1.2 percent (83 percent of the cases showed no difference). Table 4 (rural aerosol) indicated a total average difference (overprediction) of 1.1 percent. However, the maximum overprediction is only two rounds (4.5 percent to 16.6 percent), and 88 percent of the cases were in perfect agreement.

Note that the best agreement in tables 2, 3, and 4 lies in the visible region (perfect agreement) and in the near-infrared wavelengths, where the KWIK model has demonstrated its best munition prediction capabilities. Also, note that most of the differences occur with the lower visibility estimates (1.5 and 6.0 km) but visibilities over 14 km (for urban aerosol) or 24 km (for maritime and rural aerosols) show less sensitivity to visibility estimates. Overall, XTRAN does a very good job, as verified by the data in tables 1, 2, 3, and 4, of estimating the transmittance values used in SKWIK to determine munition expenditures.

TABLE 2. ACTUAL AND PERCENT DIFFERENCE IN MUNITION EXPENDITURES BETWEEN SKWIK AND KWIK CALCULATIONS FOR MARITIME AEROSOL

	Visible	Near IR	Mid IR	Far IR
	Visibility = 1.5 km (estimated as 2.3 km)			
Rounds Diff. :	0	0	+2	+2
Percent Diff.:	0	0	5.0	5.3
	Visibility = 6 km (estimated as 10 km)			
Rounds Diff. :	0	0	0	+2
Percent Diff.:	0	0	0	4.3
	Visibility = 14 km (estimated as 10 km)			
Rounds Diff. :	0	0	-2	0
Percent Diff.:	0	0	-3.6	0
	Visibility = 15 km (estimated as 20 km)			
Rounds Diff. :	0	0	+7	0
Percent Diff.:	0	0	5.1	0
	Visibility = 24 km (estimated as 20 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 25 km (estimated as 30 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0

TOTAL AVERAGE DIFFERENCE = 0.67%

TABLE 3. ACTUAL AND PERCENT DIFFERENCE IN MUNITION EXPENDITURES BETWEEN SKWIK AND KWIK CALCULATIONS FOR URBAN AEROSOL

	Visible	Near IR	Mid IR	Far IR
	Visibility = 1.5 km (estimated as 2.3 km)			
Rounds Diff. :	0	+2	+2	+2
Percent Diff.:	0	14.3	4.3	5.0
	Visibility = 6 km (estimated as 10 km)			
Rounds Diff. :	0	0	0	+2
Percent Diff.:	0	0	0	4.2
	Visibility = 14 km (estimated as 10 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 15 km (estimated as 20 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 24 km (estimated as 20 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 25 km (estimated as 30 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0

TOTAL AVERAGE DIFFERENCE = 1.2%

TABLE 4. ACTUAL AND PERCENT DIFFERENCE IN MUNITION EXPENDITURES BETWEEN SKWIK AND KWIK CALCULATIONS FOR RURAL AEROSOL

	Visible	Near IR	Mid IR	Far IR
	Visibility = 1.5 km (estimated as 2.3 km)			
Rounds Diff. :	0	+2	+2	+2
Percent Diff.:	0	16.6	4.5	5.3
	Visibility = 6 km (estimated as 10 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 14 km (estimated as 10 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 15 km (estimated as 20 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 24 km (estimated as 20 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0
	Visibility = 25 km (estimated as 30 km)			
Rounds Diff. :	0	0	0	0
Percent Diff.:	0	0	0	0

TOTAL AVERAGE DIFFERENCE = 1.1%

6. CONCLUSION

The data presented here show that the XTRAN algorithm can be used with very good accuracy to compute extinction and transmittance values for maritime, urban, and rural aerosols, as well as rain and some snow conditions. The main advantage of XTRAN lies in its practical usefulness because of its size (one-eighth the size of XSCALE) and rapid execution.

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APPENDIX A. EXTINCTION DATA FOR MARITIME, URBAN, AND RURAL AEROSOLS

1. VISIBLE WAVELENGTH DATA FOR ALL AEROSOL

Visible (0.55 μm) extinction data for all air masses for a threshold contrast of 0.10 and visibilities of 2.3, 10, 20, and 30 km is given by equation (5) in the text, and may be restated as

$$K_v = \frac{2.3}{Vis} K_t \qquad \text{(A-1)}$$

where K_v is the extinction coefficient for a particular wavelength and visual range Vis, and K_t is the factor for scaling extinction at 0.55 μm to extinction at a particular wavelength. K_t values are taken from the RHDATA file and normalized to 1.0000 for visible wavelengths.

Therefore, the extinction coefficients for all aerosols at visible wavelengths (K_t = 1.0000) and for 2.3, 10, 20, and 30 km visibility (Vis), respectively, is

$$K2.3 = 1.0000 \qquad \text{(A-2)}$$

$$K10 = 0.2300 \qquad \text{(A-3)}$$

$$K20 = 0.1150 \qquad \text{(A-4)}$$

$$K30 = 0.0766 \qquad \text{(A-5)}$$

2. MARITIME AEROSOL

The following K_v extinction relationships are given for maritime aerosol at near- (1.06 μm), mid- (3.75 um), and far-infrared (10.6 μm) wavelengths, respectively.

For near-infrared wavelengths and 0.10 threshold contrast value the K_v relationship for maritime aerosol is given by equation (A-1).

For mid- and far-infrared wavelengths and 0.05 threshold contrast value:

$$K_v = \frac{3.00}{Vis} K_t \qquad \text{(A-6)}$$

Equations (A-1) and (A-6) were used with the K_t values from the RHDATA file to produce the extinction coefficients for Vis (visibility) values of 2.3, 10, 20, and 30 km. Tables A-1, A-2, and A-3 show maritime aerosol extinction coefficients for the above visibilities at an RH range of 0 to 95 percent for near-, mid-, and far-infrared wavelengths, respectively. Tables A-4, A-5, and A-6 (for urban aerosol) and tables A-7, A-8, and A-9 (for rural aerosol) contain the same tvpe of extinction data as tables A-1, A-2, and A-3.

TABLE A-1. MARITIME AEROSOL EXTINCTION DATA FOR NEAR-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.70297	0.16168	0.08084	0.05385
50	0.72355	0.16642	0.08321	0.05542
70	0.77089	0.17730	0.08865	0.05905
80	0.87538	0.20134	0.10069	0.06705
90	0.88017	0.20244	0.10122	0.06742
95	0.90693	0.20859	0.10430	0.06947

TABLE A-2. MARITIME AEROSOL EXTINCTION DATA FOR MID-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.37450	0.08643	0.04321	0.02881
50	0.40370	0.09316	0.04658	0.03105
70	0.49499	0.11423	0.05711	0.03808
80	0.77029	0.17780	0.08888	0.05925
90	0.84009	0.19387	0.09693	0.06462
95	0.95605	0.22063	0.11031	0.07354

TABLE A-3. MARITIME AEROSOL EXTINCTION DATA FOR FAR-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.10877	0.02510	0.01255	0.00837
50	0.11214	0.02588	0.01294	0.00863
70	0.12687	0.02928	0.01464	0.00976
80	0.19911	0.04595	0.02297	0.01532
90	0.23153	0.05343	0.02672	0.01781
95	0.28782	0.06642	0.03362	0.02214

TABLE A-4. URBAN AEROSOL EXTINCTION DATA FOR NEAR-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.47095	0.10832	0.05416	0.03607
50	0.47013	0.10813	0.05406	0.03601
70	0.46639	0.10727	0.05363	0.03573
80	0.46253	0.10638	0.05319	0.03543
90	0.46809	0.10766	0.05383	0.03586
95	0.48350	0.11121	0.05560	0.03704

TABLE A-5. URBAN AEROSOL EXTINCTION DATA FOR MID-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.18200	0.04200	0.02000	0.01400
50	0.18199	0.04199	0.02100	0.01399
70	0.18266	0.04215	0.02108	0.01405
80	0.17632	0.04069	0.02034	0.01356
90	0.17286	0.03989	0.01995	0.01330
95	0.17585	0.04058	0.02029	0.01353

TABLE A-6. URBAN AEROSOL EXTINCTION DATA FOR FAR-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.11774	0.02717	0.01359	0.00906
50	0.11769	0.02716	0.01358	0.00905
70	0.11495	0.02653	0.01326	0.00884
80	0.10433	0.02408	0.01204	0.00803
90	0.09604	0.02216	0.01108	0.00739
95	0.09387	0.02166	0.01083	0.00722

TABLE A-7. RURAL AEROSOL EXTINCTION DATA FOR NEAR-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.41943	0.09647	0.04823	0.03213
50	0.42015	0.09663	0.04832	0.03218
70	0.42171	0.09699	0.04850	0.03230
80	0.43228	0.09942	0.04971	0.03311
90	0.44207	0.10168	0.05084	0.03386
95	0.45025	0.10356	0.05178	0.03449

TABLE A-8. RURAL AEROSOL EXTINCTION DATA FOR MID-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGE

RH	K2.3	K10	K20	K30
0	0.12943	0.02987	0.01493	0.00956
50	0.13052	0.03012	0.01506	0.01004
70	0.13420	0.03097	0.01548	0.01032
80	0.14958	0.03452	0.01726	0.01151
90	0.14983	0.03457	0.01729	0.01153
95	0.15072	0.03478	0.01739	0.01159

TABLE A-9. RURAL AEROSOL EXTINCTION DATA FOR FAR-INFRARED WAVELENGTHS AT 2.3, 10, 20, AND 30 KM VISIBILITY FOR 0 TO 95% RH RANGES

RH	K2.3	K10	K20	K30
0	0.10499	0.02423	0.01211	0.00808
50	0.10433	0.02408	0.01204	0.00803
70	0.10351	0.02389	0.01194	0.00796
80	0.10014	0.02311	0.01155	0.00770
90	0.09069	0.02093	0.01046	0.00698
95	0.08732	0.02015	0.01008	0.00672

APPENDIX B. EXTINCTION DATA FOR FOG ONE (HEAVY ADVECTION) AND FOG TWO (MODERATE ADVECTION) AEROSOL

Equations (A-1) and (A-6) in appendix A can also be applied to aerosol fog one and fog two for visible, near-, mid-, and far-infrared wavelengths. Since RH is 100 percent for both of these aerosols, the extinction coefficient from the RHDATA file (K_t) will be the same for all visibility ranges within the same wavelength.

1. VISIBLE WAVELENGTHS

Equations (A-2), (A-3), (A-4) and (A-5) in appendix A also apply for fog one and fog two visible (0.55 μm) coefficients for 2.3, 10, 20, and 30 km visibilities.

2. FOG ONE EXTINCTION COEFFICIENTS

The following extinction coefficients for near- (1.06 μm), mid- (3.75 μm), and far-infrared (10.6 μm) wavelengths are for visibilities of 2.3 (K2.3), 10 (K10), 20 (K20), and 30 (K30) km.

2.1 Near-Infrared Wavelengths

The following equations are extinction coefficients for near-infrared wavelengths. Equation (A-1) in appendix A was used to produce the extinction values, with K_t = 1.01750.

$$K2.3 = 1.01750 \quad \text{(B-1)}$$

$$K10 = 0.23402 \quad \text{(B-2)}$$

$$K20 = 0.11701 \quad \text{(B-3)}$$

$$K30 = 0.07801 \quad \text{(B-4)}$$

2.2 Mid-Infrared Wavelengths

The extinction coefficients for these wavelengths were derived from equation (A-6) in appendix A, with K_t = 1.0780.

$$K2.3 = 1.40609 \quad \text{(B-5)}$$

$$K10 = 0.32340 \quad \text{(B-6)}$$

$$K20 = 0.16170 \quad \text{(B-7)}$$

$$K30 = 0.10780 \quad \text{(B-8)}$$

2.3 Far-Infrared Wavelengths

Equation (A-6) in appendix A was used to determine the following extinction coefficients, where K_t = 1.1559.

K2.3	= 1.50770	(B-9)
K10	= 0.34677	(B-10)
K20	= 0.17338	(B-11)
K30	= 0.11559	(B-12)

3. FOG TWO EXTINCTION COEFFICIENTS

3.1 Near-Infrared Wavelengths

Using equation (A-1) and K_t = 1.0518,

K2.3	= 1.0518	(B-13)
K10	= 0.03155	(B-14)
K20	= 0.12096	(B-15)
K30	= 0.08064	(B-16)

3.2 Mid-Infrared Wavelengths

Using equation (A-6) and K_t = 1.4527

K2.3	= 1.89483	(B-17)
K10	= 0.43581	(B-18)
K20	= 0.21791	(B-19)
K30	= 0.14527	(B-20)

3.3 Far-Infrared Wavelengths

Using equation (A-6) and K_t = 2.1601,

K2.3	= 2.81752	(B-21)
K10	= 0.64803	(B-22)
K20	= 0.32402	(B-23)
K30	= 0.21601	(B-24)

APPENDIX C. EXTINCTION CALCULATIONS FOR RAIN, FALLING AND BLOWING SNOW

1. RAIN EXTINCTION CALCULATIONS

The average rain rate (RNRT) for the three rain categories is given below.

$$\text{Drizzle: RNRT} = 0.5 \text{ mm/h} \quad (C\text{-}1)$$

$$\text{Widespread: RNRT} = 5.0 \text{ mm/h} \quad (C\text{-}2)$$

$$\text{Thunderstorm: RNRT} = 25.0 \text{ mm/h} \quad (C\text{-}3)$$

Rain extinction coefficients for drizzle (Kdr), widespread (Kwd), and thunderstorm (Kth) are derived as

$$Kdr = 0.5089 \, (RNRT)^{0.63} \quad (C\text{-}4)$$

$$Kwd = 0.3201 \, (RNRT)^{0.63} \quad (C\text{-}5)$$

$$Kth = 0.1635 \, (RNRT)^{0.63} \quad (C\text{-}6)$$

2. FALLING AND BLOWING SNOW EXTINCTION (FOR RH < 95 PERCENT)

2.1 Falling snow (windspeed < 5 m/s)

The snow particle radius (RBAR) is dependent on temperature (TEMP), degrees Celsius, as follows.

$$\text{If } TEMP \leq -15, \quad RBAR = 100. \quad (C\text{-}7)$$

$$\text{If } -15 < TEMP < 0, \quad RBAR = (250. + 10.(TEMP)) \quad (C\text{-}8)$$

$$\text{If } 0 \leq TEMP < 2, \quad RBAR = (250. + 25.(TEMP)) \quad (C\text{-}9)$$

$$\text{If } TEMP \geq 2, \quad RBAR = 300. \quad (C\text{-}10)$$

2.2 Blowing Snow (Windspeed ≥ 5 m/s)

For blowing snow RBAR is set to 100 cm.

The extinction coefficient for falling or blowing snow (RH < 95 percent) is derived from the following expression.

$$K_{sn} = (\exp(-0.88C) + 1)1.96/Vis \quad (C\text{-}11)$$

where

$$C = 1E - 5(2\pi \, RBAR)RD/WAVE/Vis \quad (C\text{-}12)$$

WAVE is the midband wavelength in micrometers (0.55 μm for visible, 1.06 μm for near-, 3.75 μm for mid-, and 10.6 μm for far-infrared) and Vis is the visibility in kilometers. RD, the detector radius, is set to 10 cm.

APPENDIX D. XTRAN COMPUTER SOURCE CODE IN FORTRAN 77

```
C     MAIN PROGRAM XTRAN.FOR
C  *  Designed and developed by Ricardo Pena (Penya) 06/06/90.
C *** XTRAN is a program designed to calculate the atmospheric transmittance
C     due to natural aerosols using the subroutine XTRAN, which is an abre-
C     viated code based on XSCALE. XTRAN determines the atmospheric extinction
C     coefficient EXT. The elevation angle of target from observer with respect
C     to the horizontal is assumed to be zero.
C
C **  INPUTS      (ALL REAL VALUES)     FORMAT (10X,6F10.3)
C     KEYWORD       COLS.   VARIABLE     DESCRIPTION:
C---------------------------------------------------------------------------
C      DATA         1-4                 REQUIRED INPUT DATA
C                  11-20     FOG   -    ADVERSE WEATHER SELECTION:
C                                       1. = CORRECT FOR HAZ/FOG MARITIME
C                                            (ARCTIC & POLAR) AIR MASS.
C                                       2. = CORRECT FOR HAZ/FOG URBAN
C                                            AIR MASS.
C                                       3. = CORRECT FOR HAZ/FOG RURAL
C                                            (CONTINENTAL POLAR) AIR MASS.
C                                       4. = CORRECT FOR FOG ONE (HEAVY
C                                            ADVECTION).
C                                       5. = CORRECT FOR FOG TWO (MODERATE
C                                            RADIATION).
C                                       6. = CORRECT FOR RAIN (DRIZZLE).
C                                       7. = CORRECT FOR RAIN (WIDESPREAD)
C                                       8. = CORRECT FOR RAIN (THUNDERSTORM).
C                                       9. = CORRECT FOR SNOW (FALLING OR
C                                            BLOWING SNOW) (R. HUM.<95%).
C                 21-30     VS    -   LOS VISIBILITY (KM).
C                 31-40     RO    -   AMBIENT RELATIVE HUMIDITY (%).
C                 41-50     S3    -   WINDSPEED (METERS/SEC).
C                 51-60     TEMP  -   AMBIENT TEMPERATURE (DEG. C).
C                 61-70     SRNG  -   SLANT RANGE OF OBSERVER TO TARGET (KM).
C
C      NEXT         1-4               BEGINNING OF EXECUTION FOR MULTIPLE
C                                     DATA SETS.
C
C      DONE         1-4               SIGNIFIES THE LAST OR ONLY DATA SET
C                                     READ. MUST BE THE LAST RECORD READ.
C
      CHARACTER*4 ID(3),NAME
      DIMENSION WAVE(4),RV(6)
      DATA TWOPI/6.283185307/
      DATA WAVE/0.55, 1.06, 3.75, 10.591/
      DATA ID/'DATA','NEXT','DONE'/
```

```
C
C  READ DATA INPUT:
 20    CONTINUE
       READ(5,900) NAME,(RV(K), K=1,6)
       IF (NAME .EQ. ID(1)) GO TO 30
       IF (NAME .EQ. ID(2)) GO TO 50
       IF (NAME .EQ. ID(3)) GO TO 40
 30    CONTINUE
       FOG=RV(1)
       IFOG=FOG
       VS=RV(2)
       RO=RV(3)
       S3=RV(4)
       TEMP=RV(5)
       SRNG=RV(6)
       GO TO 20
C
C  LIST INPUTS:
 40    CONTINUE
       IDONE =1
 50    CONTINUE
       WRITE(6,300)
       WRITE(6,200)
       WRITE(6,350)
       WRITE(6,500)
       WRITE(6,370)
       WRITE(6,600)
       IF(IFOG .EQ. 1) WRITE(6,601)
       IF(IFOG .EQ. 2) WRITE(6,602)
       IF(IFOG .EQ. 3) WRITE(6,603)
       IF(IFOG .EQ. 4) WRITE(6,604)
       IF(IFOG .EQ. 5) WRITE(6,605)
       IF(IFOG .EQ. 6) WRITE(6,606)
       IF(IFOG .EQ. 7) WRITE(6,607)
       IF(IFOG .EQ. 8) WRITE(6,608)
       IF(IFOG .EQ. 9) WRITE(6,609)
       WRITE(6,370)
       WRITE(6,710) VS
       WRITE(6,720) RO
       WRITE(6,730) S3
       WRITE(6,740) TEMP
       WRITE(6,750) SRNG
       WRITE(6,300)
C * VISIBILITY ADJUSTMENT:
       IF(VS .GE. 25.) VIS=30.
       IF(VS .LT. 25.) VIS=20.
       IF(VS .LT. 15.) VIS=10.
       IF(VS .LT. 6. ) VIS=2.3
       IF(VS .LT. 1. ) VIS=1.0
C
```

```
C * CALCULATE ATMOSPHERIC EXTINCTION (EXT):
C
      DO 100 I=1,4
      CALL XTRAN(IFOG,EXT,VS,VIS,RO,WAVE,I,S3,TEMP,TWOPI)
      IF(SRNG .GE. VS) THEN
        TRANS=0.0
        GO TO 100
      ENDIF
      TAU=SRNG*EXT
      IF(TAU .LT. 85.) THEN
        TRANS=EXP(-TAU)
      ELSE
        TRANS=0.0
      ENDIF
      TRANS=AMAX1(TRANS,0.00001)
      TRANS=AMIN1(TRANS,1.0)
      WRITE(6,820) WAVE(I)
      WRITE(6,760) EXT
      WRITE(6,800) TRANS
      WRITE(6,350)
 100  CONTINUE
      WRITE(6,390)
      IF(IDONE .EQ. 1 ) GO TO 999
      GO TO 20
C
C * FORMAT STATEMENTS:
 200  FORMAT(10X,'ATMOSPHERIC TRANSMITTANCE CALCULATION: ')
 300  FORMAT(///)
 350  FORMAT(//)
 370  FORMAT(1H )
 390  FORMAT(1H1)
 500  FORMAT(10X,'INPUT PARAMETERS:')
 600  FORMAT(10X,'ADVERSE WEATHER CONDITION:')
 601  FORMAT(10X,'HAZ/FOG, MARITIME AIR MASS')
 602  FORMAT(10X,'HAZ/FOG, URBAN AIR MASS')
 603  FORMAT(10X,'HAZ/FOG, RURAL AIR MASS')
 604  FORMAT(10X,'FOG ONE, HEAVY ADVECTION')
 605  FORMAT(10X,'FOG TWO, MODERATE RADIATION')
 606  FORMAT(10X,'RAIN, DRIZZLE')
 607  FORMAT(10X,'RAIN, WIDESPREAD')
 608  FORMAT(10X,'RAIN, THUNDERSTORM')
 609  FORMAT(10X,'SNOW (REL. HUM.< 95%)')
 710  FORMAT(10X,'VISIBILITY,KM:                         ',F5.1)
 720  FORMAT(10X,'RELATIVE HUMIDITY, %:                  ',F5.1)
 730  FORMAT(10X,'WINDSPEED, M/S:                        ',F5.1)
 740  FORMAT(10X,'AMBIENT TEMPERATURE, DEG. C:           ',F5.1)
 750  FORMAT(10X,'SLANT RANGE, KM:                       ',F5.1)
 760  FORMAT(10X,'EXTINCTION  COEFFICIENT:               ',F8.5)
 800  FORMAT(12X,'ATMOSPHERIC TRANSMITTANCE:           ',F6.5)
 820  FORMAT(10X,'WAVELENGTH, MICROMETERS:               ',F6.3)
```

```
 900  FORMAT(A4,6X,6F10.3)
 999  CONTINUE
      STOP
      END
C
      SUBROUTINE XTRAN (IFOG,EXT,VS,VIS,R0,WAVE,I,S3,TEMP,TWOPI)
C ** SUBROUTINE TO CALCULATE EXTINCTION COEFFICIENTS DUE TO NATURAL
C    AEROSOLS FOR VISIBLE, NEAR IR, MID IR, & FAR IR.     (5/8/90)
C
      DIMENSION WAVE(4)
C * I=1 TO 4 is the index for wavelengths: 0.55, 1.06, 3.75, & 10.591
C
C * VIS=1.0 MEANS THAT THE ACTUAL VISIBILITY (VS) IS LESS THAN ONE KM.
C   THE EXTINCTION VALUE IS NOT CALCULATED FOR THE VIS=1 CASE.
C
      IF(VIS .EQ. 1.0) THEN
        EXT=999.
        GO TO 1000
      ENDIF
      GO TO (100,200,300,400,500,600,600,600,700) IFOG
C * CORRECTION FOR MARITIME AEROSOL (IFOG=1):                          XTRAN 10
 100  CONTINUE
      IF(I .EQ. 1) THEN
         EXT=2.303/VS
         GO TO 1000
C * NEAR IR Extinction (10% Threshold Contrast):
      ELSE IF(I .EQ. 2) THEN
          IF(VIS .EQ. 2.3) THEN
          EXT=0.702969+0.434713*R0-0.241279E-01*R0**2+0.489425E-03*
     1         R0**3-0.43102547E-05*R0**4+0.13970539E-07*R0**5
        ELSE IF(VIS .EQ. 10.) THEN
          EXT=0.16188842-0.47434827E-03*R0+0.10792305E-04*R0**2
        ELSE IF(VIS .EQ. 20.) THEN
          EXT=0.80943118E-01-0.23695936E-03*R0+0.53943016E-05*R0**2
        ELSE IF(VIS .EQ. 30.) THEN
          EXT=0.53934697E-01-0.16439958E-03*R0+0.36818869E-05*R0**2
        ENDIF
C ** MID IR Extinction (5% Threshold Contrast):
      ELSE IF(I .EQ. 3) THEN
        IF(VIS .EQ. 2.3) THEN
          EXT=0.37449492+0.127212723E+01*R0-0.70787653E-01*R0**2+
     1         0.14406625E-02*R0**3-0.12751449E-04*R0**4+0.41612448
     2         E-07*R0**5
        ELSE IF(VIS .EQ. 10.) THEN
          EXT=0.86084715E-01+0.24372478E-02*R0-0.84868095E-04*R0**2
     1       +0.80744837E-06*R0**3
        ELSE IF(VIS .EQ. 20.) THEN
          EXT=0.4303717E-01+0.12203131E-02*R0-0.42477688E-04*R0**2
     2       +0.40400577E-06*R0**3
        ELSE IF(VIS .EQ. 30.) THEN
```

```
         EXT=0.30121460E-01-0.86086670E-03*R0+0.14852113E-04*R0**2
       ENDIF
C ** FAR IR Extinction (5% Threshold Contrast):
      ELSE IF(I .EQ. 4) THEN
        IF(VIS .EQ. 2.3) THEN
          EXT=0.10877143-0.36226721E+02*R0+0.24637063E+01*R0**2
     1       -0.65918926E-01*R0**3+0.86910543E-03*R0**4-0.56553248
     2       E-05*R0**5+0.14548426E-07*R0**6
        ELSE IF(VIS .EQ. 10.) THEN
          EXT=0.25261024E-01-0.64383085E-01*R0+0.28208802E-02*R0**2
     1       -0.39837549E-04*R0**3+0.18263068E-06*R0**4
        ELSE IF(VIS .EQ. 20.) THEN
          EXT=0.12630209E-01-0.32088588E-01*R0+0.14060241E-02*R0**2
     2       -0.19858198E-04*R0**3+0.91048408E-07*R0**4
        ELSE IF(VIS .EQ. 30.) THEN
          EXT=0.84236782E-02-0.21460595E-01*R0+0.94027692E-03*R0**2
     1       -0.13278993E-04*R0**3+0.60876197E-07*R0**4
        ENDIF
      ENDIF
      GO TO 1000
C ** CORRECTION FOR URBAN AEROSOLS (IFOG=2):                          XTRAN 20
  200 CONTINUE
      IF(I .EQ. 1) THEN
         EXT=2.303/VS
         GO TO 1000
C ** NEAR IR (10% Threshold Contrast):
      ELSE IF(I .EQ. 2) THEN
          IF(VIS .EQ. 2.3) THEN
            EXT=0.470469+0.458491E-02*R0-0.138345E-03*R0**2+
     1          0.987225E-06*R0**3
          ELSE IF(VIS .EQ. 10.) THEN
            EXT=0.10456311+0.99970964E-04*R0
          ELSE IF(VIS .EQ. 20.) THEN
            EXT=0.52280321E-01+0.49978415E-04*R0
          ELSE IF(VIS .EQ. 30.) THEN
            EXT=0.34820473E-01+0.33340304E-04*R0
          ENDIF
C ** MID IR Extinction (5% Threshold Contrast):
      ELSE IF(I .EQ. 3) THEN
          IF(VIS .EQ. 2.3) THEN
            EXT=0.181672+0.223595E-02*R0-0.649097E-04*R0**2+
     1          0.445258E-06*R0**3
          ELSE IF(VIS .EQ. 10.) THEN
            EXT=0.409405E-01+0.246151E-04*R0
          ELSE IF(VIS .EQ. 20.) THEN
            EXT=0.196819E-01+0.214857E-04*R0
          ELSE IF(VIS .EQ. 30.) THEN
            EXT=0.13642567E-01+0.82808624E-05*R0
          ENDIF
C ** FAR IR Extinction (5% Threshold Contrast):
```

```
      ELSE IF(I .EQ. 4) THEN
           IF(VIS .EQ. 2.3) THEN
             EXT=0.12040912-0.16526281E-03*R0
           ELSE IF(VIS .EQ. 10.) THEN
             EXT=0.27787235E-01-0.38140694E-04*R0
           ELSE IF(VIS .EQ. 20.) THEN
             EXT=0.13896850E-01-0.19114772E-04*R0
           ELSE IF(VIS .EQ. 30.) THEN
             EXT=0.92638688E-02-0.12733592E-04*R0
           ENDIF
      ENDIF
      GO TO 1000
C ** CORRECTION FOR RURAL AEROSOLS (IFOG=3):                          XTRAN 30
 300  CONTINUE
      IF(I .EQ. 1) THEN
        EXT=2.303/VS
        GO TO 1000
C ** NEAR IR Extinction (10% Threshold Contrast):
      ELSE IF(I .EQ. 2) THEN
        IF(VIS .EQ. 2.3) THEN
            EXT=0.419134+0.292229E-02*R0-0.910602E-04*R0**2+
     1           0.693381E-06*R0**3
          ELSE IF(VIS .EQ. 10.) THEN
            EXT=0.92234926E-01+0.14522439E-03*R0
          ELSE IF(VIS .EQ. 20.) THEN
            EXT=0.46116508E-01+0.72625335E-04*R0
          ELSE IF(VIS .EQ. 30.) THEN
            EXT=0.30718057E-01+0.48360044E-04*R0
          ENDIF
      GO TO 1000
C ** MID IR EXTINCTION (5% Threshold Contrast):
      ELSE IF (I .EQ. 3) THEN
           IF(VIS .EQ. 2.3) THEN
             EXT=0.12900+0.316817E-02*R0-0.970693E-04*R0**2+
     1           0.73279779E-06*RC**3
           ELSE IF(VIS .EQ. 10.) THEN
             EXT=0.25575225E-01+0.15271168E-03*R0
           ELSE IF(VIS .EQ. 20.) THEN
             EXT=0.12783289E-01+0.76398985E-04*R0
           ELSE IF(VIS .EQ. 30.) THEN
             EXT=0.82117356E-02+0.54546589E-04*R0
           ENDIF
C** FAR IR EXTINCTION (5% Threshold Contrast)
      ELSE IF(I .EQ. 4) THEN
           IF(VIS .EQ. 2.3) THEN
            EXT=0.104671+0.200045E-02*R0-0.575152E-04*R0**2+
     1          0.385649E-06*R0**3
           ELSE IF(VIS .EQ. 10.) THEN
             EXT=0.23642112E-01+0.55895247E-05*R0
           ELSE IF(VIS .EQ. 20.) THEN
```

```
            EXT=0.11815846E-01+0.28406062E-05*RO
          ELSE IF(VIS .EQ. 30.) THEN
            EXT=0.78841036E-02+0.18164473E-05*RO
          ENDIF
      ENDIF
      GO TO 1000
 400  CONTINUE
C
C **  EXTINCTION COEFFICIENT FOR FOG ONE (HEAVY ADVECTION):            XTRAN 40
C **  RELATIVE HUMIDITY MUST BE 100% FOR FOG ONE. (IFOG=4)
C
      IF(IFOG .EQ. 4 .AND. RO .EQ. 100.) THEN
        IF(I .EQ. 1) EXT=2.303/VS*1.0000
        IF(I .EQ. 2) EXT=2.303/VS*1.0175
        IF(I .EQ. 3) EXT=2.996/VS*1.0780
        IF(I .EQ. 4) EXT=2.996/VS*1.1559
        GO TO 1000
      ELSE
        EXT=999.
        GO TO 1000
      ENDIF
 500  CONTINUE
C
C ** EXTINCTION COEFFICIENT FOR FOG TWO (MODERATE RADIATION):          XTRAN 50
C ** RELATIVE HUMIDITY MUST BE 100% FOR FOG TWO.(IFOG=5)
C
      IF(IFOG .EQ. 5 .AND. RO .EQ. 100.) THEN
        IF(I .EQ. 1) EXT=2.303/VS*1.0000
        IF(I .EQ. 2) EXT=2.303/VS*1.0518
        IF(I .EQ. 3) EXT=2.996/VS*1.4527
        IF(I .EQ. 4) EXT=2.996/VS*0.21601
        GO TO 1000
      ELSE
        EXT=999.
        GO TO 1000
      ENDIF
 600  CONTINUE
C
C ** EXTINCTION COEFFICIENT (EXT) DUE TO RAIN                          XTRAN 60
C
C     IFOG=6 FOR DRIZZLE; IFOG=7 FOR WIDESPREAD; IFOG=8 FOR THUNDERSTORM.
C ** SET RAIN RATE (RNRT) IN MM/HR:
      RNRT=0.
      IF(IFOG .EQ. 6) THEN
        RNRT=0.5
        EXT=0.5089*RNRT**0.63
        GO TO 1000
      ENDIF
      IF(IFOG .EQ. 7) THEN
        RNRT=5.0
```

```
        EXT=0.3201*RNRT**0.63
        GO TO 1000
      ENDIF
      IF(IFOG .EQ. 8) THEN
        RNRT=25.
        EXT=0.1635*RNRT**0.63
        GO TO 1000
      ENDIF
 700  CONTINUE
C
C ** EXTINCTION COEFFICIENT FOR SNOW (FOR REL. HUM. <95% ONLY)          XTRAN 70
C
C ** IF WINDSPEED < 5 M/S, USE "FALLING SNOW" VALUE FOR SNOW PARTICLE
C    SIZE RBAR. (IFOG=9)
      IF(RO .GT. 95.) THEN
        EXT=999.
        GO TO 1000
      ENDIF
      IF( S3 .LT. 5.) THEN
        IF(TEMP .LE. -15.) RBAR=100.
        IF(TEMP .GT. -15. .AND. TEMP .LT. 0.) RBAR=(250.+10.*TEMP)
        IF(TEMP .GE. 0. .AND. TEMP .LT. 2.) RBAR=(250.+25.*TEMP)
        IF(TEMP .GE. 2.) RBAR=300.
C ** IF WINDSPEED >5 M/S, USE "BLOWING SNOW" VALUE FOR RBAR.
      ELSE
        RBAR=100.
      ENDIF
      RD=10.
C ** VS IS THE ACTUAL LOS VISIBILITY.
      C=1.E-5*TWOPI*RBAR*RD/WAVE(I)/VS
      EXT=(EXP(-0.88*C)+1.)*1.96/VS
 1000 CONTINUE
      RETURN
      END
```

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