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ILUM CODE: SOLAR AND LUNAR FLUX CALCULATIONS FOR MULTI-CLOUD LAYERED ATMOSPHERES

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ABSTRACT

The computer code ILUM computes solar/lunar illumination received at the ground as a function of geographical location, date, standard time, and meteorological conditions. Both the computational method and program logic are described.

1. INTRODUCTION

The transfer and absorption of visible radiation in the atmosphere are the processes of primary importance in calculating the contrast between targets and natural background. Electro-optical and millimeter wave devices incorporated into modern weapons systems are strongly influenced by the battlefield environment. Battlefield environmental factors such as fog, cloud, smoke and fire products can seriously degrade system performance.

To make atmospheric transmittance predictions, computer codes based on extinction[1] or single-scattering[2] to the transport problem have widely been used. Light propagation in the atmosphere, however, is actually a multiple scattering process in which the radiation scattered by one element can be scattered again by another element. As shown by Bugnolo,[3] even for unit optical thickness there is a significant probability of triple scattering in the forward direction. Advanced computational methods employing discrete-ordiantes finite-element algorithms are adequate to solve the problem of solar energy transport thorugh an aerosol-loaded atmosphere.[4] Unfortunately, because of the computer memory requirements and the execution time limitations, these methods are not implementable in the real-time, battlefield conditions. The work reported here describes a new computer code that fills, in part, the need for a fast-running, flexible algorithm. The computer code ILUM computes solar/lunar illumination (Watt/m²) received at the ground as a function of geographical location, date, standard time, and meteorological conditions. To model the different states of cloudiness, we consider a three-layer atmosphere, with each layer represented in terms of the cloud amount and cloud thickness or type. The albedo option allows one to account for realistic albedo conditions of the ground surface. Concurrently, an average albedo option can be selected.

ILUM is based on the work of R. Shapiro[5], which arose from the Air Force requirement for the development of technical decision aids for infrared precision guided munitions. Shapiro's approach is essentially the doubling method employing three-layer atmospheres. The reflectivity and transmittivity coefficients are determined by a third-order fit to experimental data in the visible and IR spectral ranges.

2. MODEL STRUCTURE

The model calculations, developed by Shapiro[5], make use of a simple two-stream approximation in conjunction with tabulated mean climatological reflection and transmission coefficients. In the doubling method, the reflection and transmission function of the layer consisting of n sublayers, are computed by means of the known reflection and transmission functions in the separate layers. The case with $n = 3$ is the simplest geometry that makes use of the standard cloud code information which categorizes clouds into high, middle, and low cloud types. In this section, we give the relevent formulas of Shapiro and adapt his work to deal with solar or lunar illumination.

2.1 Extraterrestrial Radiation on a Horizontal Surface

For the model atmosphere composed of n layers, the energy conservation at k-th layer yields

$$R_k + T_k + A_k = 1 \quad , \tag{1}$$

where R_k, T_k, and A_k denote the fractions of reflected, transmitted, and absorbed radiation. Referring to Fig. 1, we can write a system of $2n + 2$ linear equations for X_k and Y_k, the radiation impinging upon layer $k + 1$ from above and the upward-directed radiation emanating from layer $k + 1$. The sequence of equations has the form

$$X_k = T_k X_{k-1} + R_k Y_k \tag{2}$$

$$Y_k = R_{k+1} X_k + T_{k+1} Y_{k+1} \tag{3}$$

where $T_0 = 1$, $R_0 = 0$, $T_{n+1} = T_g = 0$, and $R_{n+1} = R_g$ (the ground albedo).

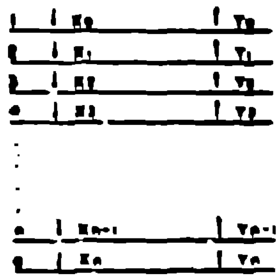

Figure 1. Flux of solar radiation through an atmosphere consisting of n homogeneous layers and a ground surface.

As the general solution to the system of Eqs. (2) and (3) is contained in Ref. (5), we restrict ourselves to giving the illumination on a horizontal surface in the case of $n = 3$. Expressed in terms of extraterrestrial radiation X_0, it reads

$$X_3 = T_1 T_2 T_3 X_0 / D_2 \tag{4}$$

where

$$\begin{aligned} D_2 = 1 &- (R_1R_2 + R_2R_3 + R_3R_g) \\ &- (R_1R_3T_2^2 + R_2R_gT_3^2 + R_1R_gT_2^2T_3^2) \\ &+ (R_1R_2^2R_3 + R_2R_3^2R_g + R_1R_2R_3R_g + R_1R_3^2R_gT_2^2 \\ &+ R_1R_2^2R_gT_3^2) - R_1R_2^2R_3^2R_g \end{aligned} \tag{5}$$

It is clear from Eqs. (4) and (5) that once the extraterrestrial radiation X_0 has been determined, the problem is reduced to finding the reflectivity and transmissivity coefficients R_k and T_k for different atmospheric conditions. In addition, the knowledge of the ground albedo R_g is required.

Now, in the work of Shapiro,[5] the R_k's and T_k's are determined by fitting the meterological data with cubic polynomials of the form

$$R_k = a_0 + a_1\mu + a_2\mu^2 + a_3\mu^3 \tag{6}$$

and

$$T_k = b_0 + b_1\mu + b_2\mu^2 + b_3\mu^3 \tag{7}$$

Here, $\mu = \cos\theta$ is the cosine of the zenith angle θ. The model recognizes nine basic states: three in layer 1, two in layer 2, and four in layer 3. In addition, the bottom layer (layer 3) has a basic state consisting of smoke and/or fog occurring in conjunction with an otherwise clear layer 3. Added to these four clear-layer basic states, there are five overcast-layer basic states: thin cirrus/cirrostratus or thick cirrus/cirrostratus in layer 1, altostratus/altocumulus in layer 2, and either cumulus/cumulonimbus or stratocumulus/stratus in layer 3. All possible sky states including fractional cloudiness are represented by combinations of the basic states. Precipitation is assumed to be represented by overcast in all three layers: thick cirrus/cirrostratus in layer 1, altostratus/altocumulus in layer 2, and stratocumulus/stratus in layer 3. Numerical values of the coefficients a_i and b_i, $i = 0, 1, 2, 3$ in Eqs. (6) and (7) are contained in Ref. 5. For the ground albedo R_g, either specific values in the visible spectrum, as cited in Ref. 5, or the average value $R_g = 0.2\epsilon$ can be used.

2.2 Extraterrestrial Radiation

Since ILUM analyzes only the radiation integrated over the visible spectral range, the illumination on a horizontal surface as given by Eq. (4) requires the integrated value of X_0, the extraterrestrial radiation per unit horizontal surface. The evaluation of X_0 depends on the type of radiation one envisages. This can be solar or lunar radiation.

2.2.1 Solar Radiation

A recent book by Iqbal[6] gives up-to-date tables of the spectral distribution of solar radiation. Here, for the integrated radiation, we use the formula

$$X_0 = S(\frac{\bar{d}}{d})^2 \cos \tag{8}$$

where the solar contrast $S = 1369.2\ W/m^2$, where $(\bar{d}/d)^2$ is a function of the ellipticity of the earth's orbit and the position of the earth in its orbit around the sun. It may be expressed as

$$(\bar{d}/d)^2 = [1.000140 + 0.016726 \cos \frac{2\pi(JD-2)}{365}]^2 \tag{9}$$

where JD, the Julian Day, is 1 on January 1 and 365 on December 31. We note that the solar spectrum is partitioned in the proportion 8.03%:46.41%:45.40% into UV, visible, and IR spectral bands.

2.2.2 Lunar Radiation

The extraterrestrial lunar radiation incident at the top of the atmosphere is the result of lunar reflected sunlight. Following Ref. 2, we write for the integrated irradiance SMOON:

$$SMOON = 2.04472 \cdot 10^{-7} \cdot S \cdot ALBED \cdot PHAS(X) \quad (10)$$

where x is the phase angle for the moon, ALBED is the geometric albedo for the moon taken at the wavelength of 0.55 μm, and PHAS(X) is the phase function giving the relative intensity as a function of the phase angle. For a full moon, PHAS(X=0) = 1.

3. PROGRAM LOGIC

ILUM was designed to provide the user with the value of illumination on a horizontal surface under various atmospheric and surface conditions. The input for ILUM follows the philosophy of the EOSAEL Library. The output provides the illumination both for a specific and average surface albedo.

3.1 Input

ILUM accepts card order-independent format data. A four-letter identifier in columns 1-4 of each record assigns the numerical values that follow it to specific variables used in ILUM. The input card identifiers recognized by ILUM are DATE, SQRC, ZONE, MOON, GEOS, CLDS, ALBD, and GO. The table lists and describes each nine input record formats.

3.2 Output

Typical output files for two runs of ILUM are given. The option ISRC = 0 implies the solar illumination, ISRC = 1 the lunar illumination.

4. CONCLUSION

The Shapiro model has been extended to the case of lunar extraterrestrial radiation. Since the code ILUM requires about 3 sec CPU time on a CDC machine as compared with about 30 sec CPU time for a standard discrete-ordinate code, it may prove useful for real-time simulation and as a technical decision aid.

5. REFERENCES

1. F.X. Kneizys et. al, "Atmospheric Transmittance/Radiance: Computer Code LOWTRAN 5," AFGL-TR-80-0067 (February, 1980).

2. C.M. Lampley and W.G.M. Blättner, "E-O Sensor Signal Recognition Simulation: Computer Code Spot 1," RRA-T7809 (October, 1978).

3. D.S. Bugnolo, "On the Question of Multiple Scattering in the Troposphere," J. Geoph. Res. 65, 879 (1960).

4. A. Zardecki and S.A.W. Gerstl, "Calculations of Solar Irradiances in Clear and Polluted Atmospheres and Potential Effects on Plant Life," LA-9010-MS (October, 1981).

5. R. Shapiro, "Solar Radiative Flux Calculations from Standard Surface Meteorological Observations," AFGL-TR-82-039 (March, 1982).

6. M. Iqbal, "An Introduction to Solar Radiation," (Academic Press, New York, 1983).

TABLE 1. ILUM INPUT RECORDS

Identifier	Variables	Description
DATE	MM/DD/YY	Month/Day/Year The variable YY is not used by the code, except for typing the date at the beginning of the output file.
SORC	ISRC	(0/1) - solar/lunar source
ZONE	ITZ	(4/5/6/7/8/9/10) - Atlantic/Eastern/Central/Mountain/Pacific/Alaska/Hawaii standard time. When ITZ≠0, ITZ supersedes the parameter SM on the GEOS card.
MOON	PHS, ZN	Lunar phase and zenith angles.
GEOS		Parameters describing the location and time of the observation point:
	SLAT	Local latitude
	SLON	Local longitude
	SM	Standard meridian
	ST	Standard time
CLDS		State of cloudiness in each of three layers:
	ILR1	(1/2/3) Clear/thin Ci-Cs/thick Ci-Cs
	ILR2	(1/2) Clear/As-Ac
	ILR3	(1/2/3/4) Clear/fog-smoke/Sc-St/Cu-Cs
ALBD	IALB	Surface albedo identifier
GO	None	Signifies to begin execution

TABLE 2. EXAMPLE OF OUTPUT

ISRC = 0

```
**********************************************************

CODE: ILUM
ILLUMINATION FROM SURFACE METEOROLOGICAL OBSERVATIONS
FOR THE DATE OF 9/28/84
DAYTIME CONDITIONS

**********************************************************

STANDARD TIME:              10H16MIN
LOCAL LATITUDE        =     30.00 DEG
LOCAL LONGITUDE       =   -100.00 DEG
FIRST LAYER     CI-CS
   - THIN CLOUD
SECOND LAYER:   AS-AC
THIRD LAYER:    F-H
SURFACE ALBEDO IDENTIFIER:  14
SOLAR ZENITH ANGLE    =     43.16 DEG

SOLAR INSOLATION      =   3.1729E+02 WATT M-2
      - AVERAGE GROUND ALBEDO =   .26

SOLAR INSOLATION      =   3.0691E+02 WATT M-2
      - GROUND ALBEDO EQUALS      .80
```

ISRC = 1

```
**********************************************************

CODE  ILUM
ILLUMINATION FROM SURFACE METEOROLOGICAL OBSERVATIONS
FOR THE DATE OF 9/28/84
NIGHTTIME CONDITIONS

**********************************************************

STANDARD TIME:              23H 0MIN
LOCAL LATITUDE        =     30.00 DEG
LOCAL LONGITUDE       =   -100.00 DEG
PHASE ANGLE           =     10.00 DEG
MOON'S ZENITH ANGLE   =     60.00DEG
FIRST LAYER:    CI-CS
   - THIN CLOUD
SECOND LAYER:   AS-AC
THIRD LAYER.    F-H
SURFACE ALBEDO IDENTIFIER:  13

LUNAR ILLUMINATION    =   3.4179E-04 WATT M-2
      - AVERAGE GROUND ALBEDO =   .26

LUNAR ILLUMINATION    =   3.7384E-04 WATT M-2
      - GROUND ALBEDO EQUALS      .40
```