ON THE COMPUTATION OF THE ACTINOMETRIC RADIATION FIELD

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RESUMEN

En un trabajo previo hemos presentado un algoritmo (J, m, w, B, $\alpha = 1.5$) que describe el Campo Actinométrico de Radiación; dadas como condiciones iniciales tres de las variables anteriores, se obtiene la cuarta variable. En el presente artículo se presenta un algoritmo más flexible. El método permite un análisis cuantitativo de las diferentes distribuciones de la constante solar junto con las funciones de transmisión utilizadas. Los resultados muestran estas relaciones para combinaciones de las funciones de entrada en términos de un indicador de todo el proceso, en este caso, el coeficiente B de la turbidez atmosférica. El algoritmo es entonces una técnica útil para el estudio de cualquier combinación deseada de las curvas espectrales de irradiación solar juntamente con las funciones de transmisión dadas; en esta forma las Comisiones Internacionales pueden escoger la mejor combinación y recomendarla para cálculos futuros.

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ABSTRACT

In a previous work we have shown an algorithm (J, m, w, B, $\alpha = 1.5$) which describes the Actinometric Radiation Field; given as initial conditions three of the above variables one obtains the fourth variable. In the present paper a more flexible algorithm is presented. The method enables one to make a quantitative analysis of the different solar constant distributions together with the transmission functions used. Results show these relationships for combinations of the input functions in terms of an indicator of the whole computation process, in this case, the atmospheric turbidity coefficient B. The algorithm becomes a useful technique for any desirable combination of the spectral irradiant curves together with the given transmission functions; in this way, the International Commissions may choose the best combination and recommend it for future calculations.

INTRODUCTION

In a previous paper (Galindo, I. G. and A. Muhlia V., 1970), we have shown an Algorithm (J, m, w, B, $\alpha = 1.5$) programmed in Fortran IV which describes the Actinometric Radiation Field; given as initial conditions three of the above variables, say $\{J, m, w\}$, one obtains the fourth variable B. Here J is the intensity of direct solar radiation, m the relative optical air mass, w the amount of precipitable water, B the Schüepp's turbidity coefficient, and the wavelength exponent for the dust extinction.

In the present paper we show some improvements in the computation procedure, which in turn produce a flexible Algorithm in Algol Language leading to a better interpretation and understanding of the transmission functions used for each extinction agent. By means of instruction blocks one can obtain results for any desirable instruction, for example, different "Solar Constant" distributions that are studied in terms of an indicator of the whole computation process, in this case, the turbidity coeficient B. With the information here produced one can choose different input functions (Solar Constant, transmission functions, particle size distribution, etc.) each according to the problem at hand. In other words, the comparisons made here can be the basis for new recommendations since we show quantitative relationships between different solar radiation extinction parameters not otherwise known.

GENERAL CONSIDERATIONS

Solar Constant. The spectral-irradiance curves of revisions of the Smithsonian value of the Solar Constant prepared by Nicolet (1951) and Johnson (1954) are here employed together with the spectral-irradiance curve of Labs and Neckel (1968), which was calibrated against the irradiance from melted gold at the temperature of 1,337.58°K. Reasons to include here the curve of Labs and Neckel are that according to Kuhn's work (1971), the extrapolation values of direct solar spectral observations to zero air mass made in the Antarctic lie nearer to Labs and Neckel values than to Nicolet's or Johnson's. From the work of Drummond, Hickey, Scholes and Laue (1968) one sees also that their results obtained from energies below 607 nm from aircraft measurements made at an altitude of 82 Km, are nearer to Kuhn's (11971) spectral observations (310-525; 525-630, and 630-710 nm).

Absorption due to Ozone. The ozone absorption coefficients experimentally obtained by several authors and given in the Smithsonian Tables (1951) are compared with newer ozone absorption coefficients obtained from Dütsch and given in Linke's Meteorology Handbook (Bauer, 1970). The comparison is made for the three ozone bands, the Hartley and Huggins band under 340 mm and the Chappius band between 440 and 700 mm.

Absorption due to Water Vapor, CO_2 and O_2. Although the atmospheric absorption spectrum of water vapor is extremely complicated (Goody, R. M., 1954) for purposes of computation of the actinometric intensity of solar radiation, Fowle's original results accent (Fowle, F. E., 1912) and taken in general with modifications given by different authors who accent a relationship of the form $J_{\lambda,w} = f_\lambda$ (m, w), originally given by K. Ångström (1907), i.e., the intensity of solar radiation as a function of the product of the air mass m with the precipitable water content w. This, in turn, means that a transmission function for water vapor in the atmosphere shall depend not only upon the physical abundance of water but also upon the pressure. Howard, Burch and Williams (1956), in a series of papers, took this into consideration and derived expressions for water vapor and for CO_2. A. Ångström (1964) has derived, from Fowle's laboratory measurements interpreted by McDonald (1960), an empirical formula for the absorption of water vapor that incorporates the scattering and absorption by the aerosol. However, at present, we have this approach under study for computation purposes.

For actinometric purposes, Kuhn (1971) has applied these results; one of us (Galindo, I. G., 1971) has also applied these transmission functions to actinometric calculations. Here we shall discuss two different empirical approaches to the absorption of water vapor: first the Mörikofer and Schüepp's (1951) results for spectral absorption of water vapor, CO_2 and O_2, and the integrated absorption function derived from Möller (1964), which in fact represents a whole set of functions of the type $f(m, w) = a(m, w)^b$, where a and b are coefficients.

Computation of the Attenuation of Radiation due to Scattering.

1 Rayleigh Scattering. The Rayleigh Scattering Coefficient (Rayleigh, Lord, 1899) used here is defined by the continuous function of λ :

$$a_{R,\lambda} = a_\lambda \ H = 0.00879 \ \lambda^{-4.09}, \quad \text{for all } \lambda \tag{1}$$

a contains the scalar phase function for incident unpolarized radiation (Goody, R. M., 1954) and $a_\lambda H$, with H the height of a homogeneous atmosphere computed for T = 273°K, in microns; $a_{R,\lambda}$, as Linke (in Kondratiev, K. Ya., 1969) has shown, contains the dependence of the difraction index upon wavelength.

2 Aerosol Scattering. From the original proposition of Ångström (1929), the attenuation coefficient due to scattering is

$$a_{R,D} = a_{R,\lambda} + \beta \lambda^{-\alpha} \tag{2}$$

Schüepp (1919) replaces the coefficient β defined from the above equation with a coefficient B given by

$$B = \beta \ 2^{\alpha}, \log e \tag{3}$$

B is the Schüepp's decadic turbidity coefficient referred to $\lambda = 0.5 \ \mu$ with $\alpha = 1.3$; this gives the linear relationship

$$B = 1.07 \ \beta \ \text{ referred to } \lambda = 0.5 \mu \tag{4}$$

Following Schüepp, in this work we shall take $\alpha = 1.5$ and the aerosol attenuation coefficient $a_{D,\lambda}$ given by

$$a_{D,\lambda} = B\,(2\lambda)^{-1.5}\,, \qquad \text{for all } \lambda \tag{5}$$

The Optical Air Mass. This parameter computed as a subroutine is used when necessary either to give the relative air mass m_r or the absolute air mass $m = m_r .\ p/p_o$. This aspect is discussed elsewhere in detail (Muhlia, A., Galindo & L. L. Lemoyne, 1971).

The Extinction Equation

From the above information the generalized Ångström Extinction equation may be derived

$$J_{ab}\,(\zeta) = \frac{1}{S} \int_{a=0.28\,\mu}^{b=5.0\,\mu} J_{o\lambda i}\, T_{o\lambda}^{m}\; 10^{-m_r\, a_{\Omega}(\lambda)}\; 10^{-m_r\, B\,(2\lambda)^{-1.5}}\; \underset{\lambda, CO_2\,,\, O_2,\, w}{A(m_r \cdot w)}\, d\lambda \cdot f\,(m_r\, w) \tag{6}$$

here

S = the earth-sun mean distance correction factor
$J_{ab}\,(\zeta)$ = the measured solar radiation intensity
ζ = the zenithal distance,
$i = 1, 2, 3;\ 1$ = Nicolet's Solar Constant distribution
2 = Johnson's Solar Constant distribution
3 = Labs and Neckel Solar Constant distribution
$T_{o\lambda}^{m}$ = Rayleigh transmission function
$a_{\Omega}\,(\lambda)$ = Dütsch-Ozone coefficients or the Smithsonian coefficients
$\underset{\lambda,\, w, CO_2, O_2}{A\,(m_r\, w)}$ = Mörikofer Schüepp Extinction Values for water vapor, CO_2 and O_2.
$f(m_r\, w) = 0.172\,(m_r\, w)^{0.3028}$ Möller's formula for the integrated absorption of water.

Equation (3.1) means that when one uses Möller's formula,

clearly $\underset{\lambda,\, w\,,\, CO_2, O_2}{A(m_r\, w)} = 1$.

When one wishes to use the Mörikofer and Schüepp's calculated values for the absorption of water vapor, CO_2 and O_2, then $f(m_r w) = O$.

As for the Solar Constant distributions, the indexes come once for each i-value. Also, one has combinations of the different solar constant distributions with different transmission functions, in particular for Ozone, water, CO_2 and O_2.

METHODS AND MATERIAL

Just as in (1), it is assumed that the integral Equation (6) is Riemannian:

$$\int_0^{\infty} g(\lambda)\, d\lambda = \lim_{\Delta_j \to 0} \sum_{j=1}^{\infty} g(\theta_j)\, \Delta_j \qquad (7).$$

provided this limit exists. Here $\Delta_j = \lambda_j - \lambda_{j-1}$ and θ_j is a point such that $\lambda_{j-1} \leqslant \theta_j \leqslant \lambda_j$; j = 1, 2, . . ., n; therefore, we rewrite Eq. (6) as:

$$S \cdot J_{ab}(\zeta) = \sum_{j=a}^{b} J_{0\lambda i}\, T_{0\lambda}^{m}\, 10^{-m_r a_\Omega(\lambda)}\, 10^{-m_r B(2\lambda)^{-1.5}}\, \Delta\lambda_j \cdot A(m_r \cdot w)_{\lambda,\, w,\, CO_2, O_2} \qquad (8)$$

Taking into account the different approaches to the extinction process involved, Equation (8) is transformed into

$$S \cdot J_{ab}(\zeta) = \sum_{j=a}^{n_{1i}} J_{0\lambda_i}\, T_{0\lambda}^{m}\, 10^{-m_r a_\Omega(\lambda)_{HH}}\, 10^{-m_r B(2\lambda)^{-1.5}}\, \Delta\lambda_j +$$

$$\sum_{j=n_{1i}+1}^{n_{2i}} J_{0\lambda i}\, T_{0\lambda}^{m}\, 10^{-m_r a_\Omega(\lambda)_{CH}}\, 10^{-m_r B(2\lambda)^{-1.5}}\, \Delta\lambda_j +$$

$$\sum_{j=n_{2i}+1}^{b} J_{0\lambda_i}\, T_{0\lambda}^{m}\, 10^{-m_r B(2\lambda)^{-1.5}}\, \Delta\lambda_j - f(m_r \cdot w) \qquad (9)$$

Equation (4.3) shows the Möller's formula for the integrated absorption of water; from Equation (4), $A(m_r, w)_{\lambda, w, CO_2, O_2} = 1.$

Note here the partitions corresponding to the spectral windows of the Hartley-Huggins and Chappuis Ozone absorption bands.

Due to the different intervals Δ_j given by Nicolet, Johnson and Labs and Neckel in their Solar Constant irradiance curves, the summation indexes will depend on the particular Solar Constant distribution used. When the Mörikofer-Schüepp's table is used for the spectral absorption due to water vapor, CO_2 and O_2, Equation (8) takes the form:

$$S \cdot J_{ab}(\zeta) = \sum_{j=a}^{n_{1i}} J_{o\lambda_i} T_{o\lambda}^{m} \, 10^{-m_r a_\Omega(\lambda)_{HH}} \, 10^{-m_r B(2\lambda)^{-1.5}} \Delta\lambda_j +$$

$$\sum_{j=n_1 i+1}^{n_{2i}} J_{o\lambda_i} T_{o\lambda}^{m} \, 10^{-m_r a_\Omega(\lambda)_{CH}} \, 10^{-m_r B(2\lambda)^{-1.5}} \Delta\lambda_j +$$

$$\sum_{j=n_2 1+1}^{n_{3i}} J_{o\lambda_i} T_{o\lambda}^{m} \, 10^{-m_r B(2\lambda)^{-1.5}} \cdot A(m_r \cdot w)_{w, CO_2, O_2, \Delta\lambda_i} \Delta\lambda_j + \bullet\bullet\bullet +$$

$$\sum_{j=n_{hi}+1}^{b} J_{o\lambda i} T_{o\lambda}^{m} \, 10^{-m_r B(2\lambda)^{-1.5}} A(m_r \cdot w)_{w, CO_2, O_2, \Delta\lambda_j} \Delta\lambda_j \qquad (10)$$

which means that the third summation term of Equation (9) is replaced by seven smaller summations:

$$\sum_{j=n_{2i}+1}^{b} J_{o\lambda_i} T_{o\lambda}^{m} \, 10^{-m_r B(2\lambda)^{-1.5}} \Delta\lambda_j \rightarrow \sum_{j=n_{2i}+1}^{n_{3i}} J_{o\lambda_i} T_{o\lambda}^{m} \, 10^{-m_r B(2\lambda)^{-1.5}} A(m_r w)_{w, CO_2, O_2, \Delta\lambda_j} \Delta\lambda_j +$$

$$+ \bullet\bullet\bullet + \sum_{j=n k_i + 1}^{b} J_{o\lambda_i}\, T_{o\lambda}^{m}\, 10^{-m_r\, B(2\lambda)^{-1.5}}\, A(m_r\, w)_{w,\, CO_2,\, O_2,\, \Delta\lambda_j}\, \Delta\lambda_j$$

Each summation term corresponds to the spectral windows (0.72-0.80; 0.80-1.0; 1.0-1.25; 1.25-1.5; 1.5-2.0; 2.0-3.0; > 3.0 μ). See Robinson's book (1966).

The Computation Procedure.

In Equations (9) and (10), the unknown parameter is the turbidity coefficient B. Also one forms a function P(B) defined for Equation (9), if Möller's formula is used,

$$\underset{1}{\sum_{HH}} + \underset{2}{\sum_{CH}} + \underset{3}{\sum_{D,w}} = P\,(B) \tag{11}$$

then, one compares

$$P\,(B) - J_{ab}\,(\zeta) \cdot S :: f(m_r, w)$$

the computer forms P(B) by iterations of the estimated B + Δ B until P(B) approaches closely $\varphi = f(m_r w) + J_{ab}\,(\zeta) S$; therefore it is necessary to stop the process where a very small difference is reached, i.e.

$$|\,P(B) - \varphi\,| \leqslant).001, \qquad B = B_o \tag{12}$$

(see Figure 1)

For the use of the Mörikofer-Schüepp's Table from Equation (10) one obtains

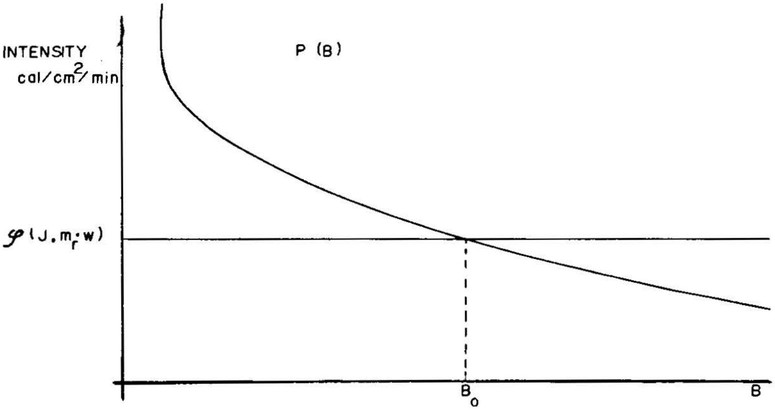

FIGURE I. THE ITERATION PROCESS TO OBTAIN AN OPTIMAL B_o, MOLLER'S CASE.

$$\underset{1}{\sum_{HH}} + \underset{2}{\sum_{CH}} + \underset{3}{\sum_{D,w}} + \underset{4}{\sum_{w}} + \cdots + \underset{9}{\sum_{w}} = P''(B; m_r \cdot w) \quad (13)$$

then,

$$P'(B) :: J_{ab}(\zeta) \cdot S$$

and

$$|P'(B) - J_{ab}(\zeta) \cdot S| \leqslant 0.001, \qquad B = B_O \qquad (14)$$

(See Figure 2)

Explanation of the Symbols

$\sum_j$ the summation terms; HH the Hartley-Huggins band; CH the Chappuis band; D a dust term; w water vapor. The upper indexes of P(B) define different intervals. B_o is the optimal B obtained through the iteration process. The running time for the whole process is about a second per B.

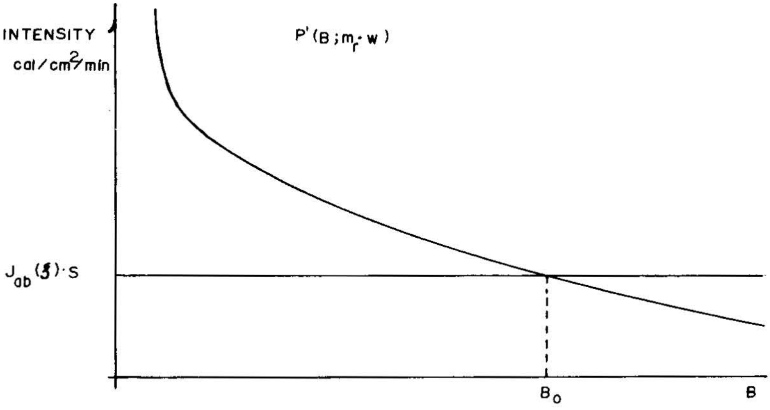

FIGURE 2 THE ITERATION PROCESS TO OBTAIN AN OPTIMAL B_0, MÖRIKOFFER — SCHÜEPP'S CASE.

In order to prove the computation process, pyrheliometric data from our network are used, but as for control, actinometric data from Basle* are also used.

RESULTS AND DISCUSSION

The Solar Constant. The Radiation Commission during the IGY reccommended to use as a Solar Constant the value given by Nicolet (1951) or by Johnson (1954), provided they are given in terms of the IPS 1956. However, as Kuhn (1971) has shown, the relative new irradiance-curve of Labs and Neckel (1968) shows closer values to those obtained by extrapolation from observational data from the Antarctic.

The algorithm presented here provides turbidity coefficients B for each distribution curve.

Table I shows a linear correlation with pairs of combinations between different Solar Constant distributions and different transmission functions for the absorption of water, CO_2 and O_2, in particular, the Mörikofer-Schüepp's (1951) values or the Möller's (1958).

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* Through the courtesy of Dr. W. Schüepp.

TABLE I – LINEAR CORRELATION IN TERMS OF THE TURBIDITY DIFFERENT SOLAR CONSTANT DISTRIBUTIONS

	$\overline{B}_x$	$\overline{B}_y$	σx	σ_y	a	b	c	N = 80
Mexico City, 1970								
MS	.086	.080	.076	.076	.080	.968	.999	N-J
MS	.086	.064	.078	.073	.064	.934	.996	N-LN
MS	.080	.064	.075	.073	.064	.965	.996	J-LN
Mexico City, 1969								
M	.144	.144	.076	.076	.144	.993	.999	N-J
MS	.123	.116	.077	.075	.116	.969	1.000	N-J
Basle, 1958								
M	.128	.127	.068	.067	.127	.990	.999	N-J
MS	.113	.106	.074	.072	.106	.971	1.000	N-J

Explanation of Symbols: $\overline{B}$ the average value of the turbidity coefficient; σ the standard deviation; a, b the linear regression coefficients, C the correlation coefficient.
MS = Mörikofer-Schüepp values; M = Möller's formula;
N-J = Nicolet-Johnson pair
N-LN = Nicolet-Labs and Neckel pair.
J-LN = Johnson-Labs and Neckel pair.

From the above data, taking the Nicolet's values as unity, one finds:

	N	J	LN	$Bx10^{-3}$
MS_{70}	1.0	– 7%	–13%	
MS_{69}	1.0	–11%		
$MS_{\text{Basle, 58}}$	1.0	–11%		
$M_{69,58}$	1.0	0		

which means that the turbidity values calculated with the Mörikofer-Schüepp's assumptions and Johnson's Solar Constant curve are lower (7-11%) with respect to Nicolet's; the Labs and Neckel distribution gives values even lower, 13%. When one uses the Möller's formula for water absorption, there is no difference in using freely any Solar Constant distribution, but this result is obvious, the Möller's formula is independent of the integrant in the integral equation. Table I shows also that the percent departure increases as the turbidity increases. The assigned value of 1.0 to Nicolet's is only for reference purposes, i.e., if one takes the Labs and Neckel calculation as 1.0, then the Nicolet's values are 13% larger, and so on. The differences reported here agree in percent with those calculated from Kuhn's work (1971, p. 48) for the Solar Constant distribution alone. That is, the computation process is correct and B in this case is a good indicator.

The Atmospheric Transparency

In order to make an analysis of the spectral extinction of the incoming solar radiation and the effects of the different transmission functions, one has to deal with absorptions of the atmospheric gases, and molecular and aerosol scattering. However, the transmission function for aerosol scattering really takes into account the aerosol absorption, and one has to speak of aerosol attenuation. These processes are studied here by separating the whole spectral window into two regions: the first one deals only with absorption due mainly to ozone and attenuation due to Rayleigh's scattering together with aerosol; the second spectral region deals mainly with water vapor absorption and the corresponding attenuation due to Rayleigh's scattering and aerosols.

1 – The Spectral Region, $\lambda < 700$ nm

From Equation (9), using the Labs and Neckel Solar Constant distribution one obtains 48 segments $\Delta\lambda_j$ that integrates the Hartley-Huggins and Chappuis Ozone absorption bands, that is, they run from 300 to 770 nm. Since water vapor absorption has a small spectral window at 700-740 nm (band a), one has to take this contribution into account, also one forms

$$\sum_{j=1}^{48} J_{o\lambda_3} T_{o\lambda}^{m} 10^{-\Omega a_{\Omega}(\lambda) m_r} 10^{-B(2\lambda)^{-1.5} m_r} A_a (m_r\ w) \Delta\lambda_j$$

here

Ω is the Ozone abundance; for Mexico City one takes usually $\Omega = .26$ cms.

$a_{\Omega}(\lambda)$ can be either the Dütsch or the Smithsonian Ozone absorption coefficients.

$A_a(m_r w) = 1$, for $m_r = 1.0$, $w = 1.0$ cm.

$= 1$, for $m_r = 2.0$, $w = 0.5$ cm.

Taking the aerosol abundance to be either B = 0.001 and B = 0.100, we obtain the results (IPS 1956, mly/min) presented in Tables II-V and Figures 5.1 to 5.4.

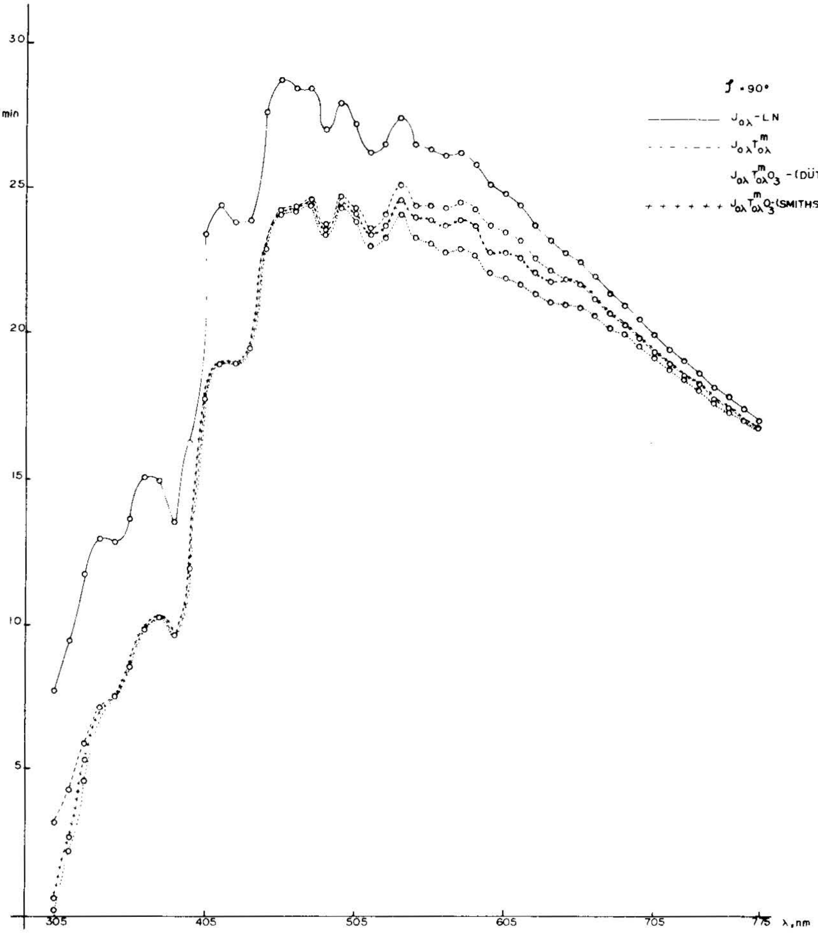

FIGURE 5.1 COMPARISON OF DÜTSCH-OZONE ABSORPTION COEFFICIENTS WITH THOSE GIVEN IN SMITHSONIAN TABLES·

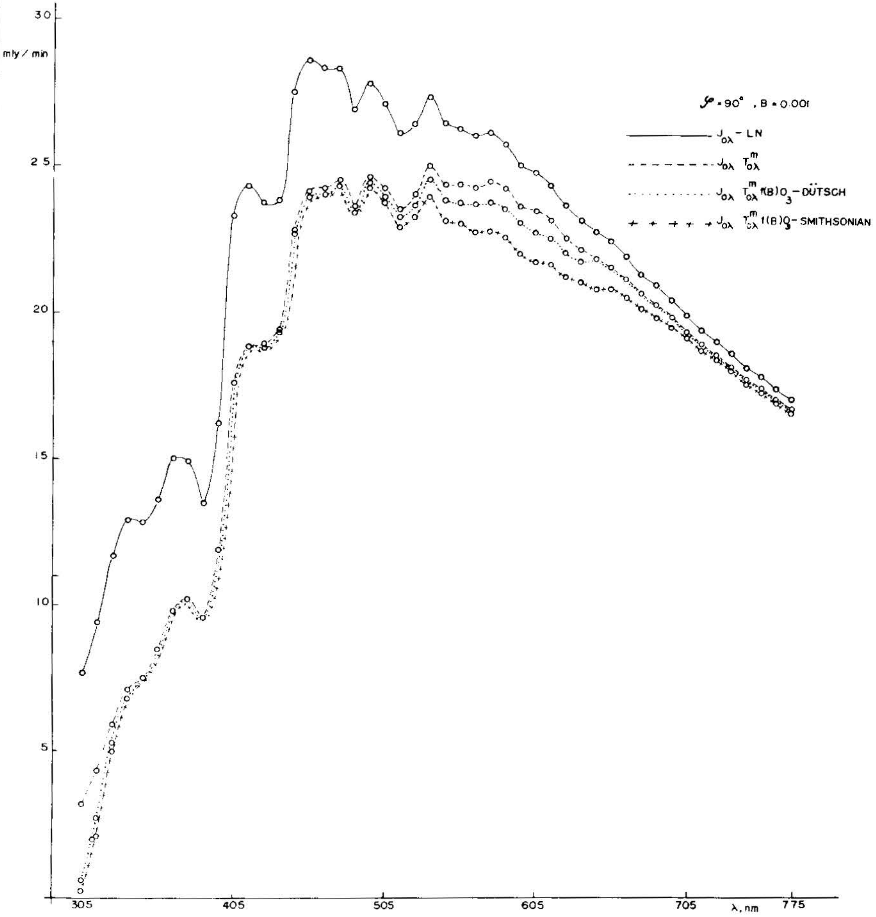

FIGURE 5 2 ATMOSPHERIC ATTENUATION DUE TO AEROSOLS.

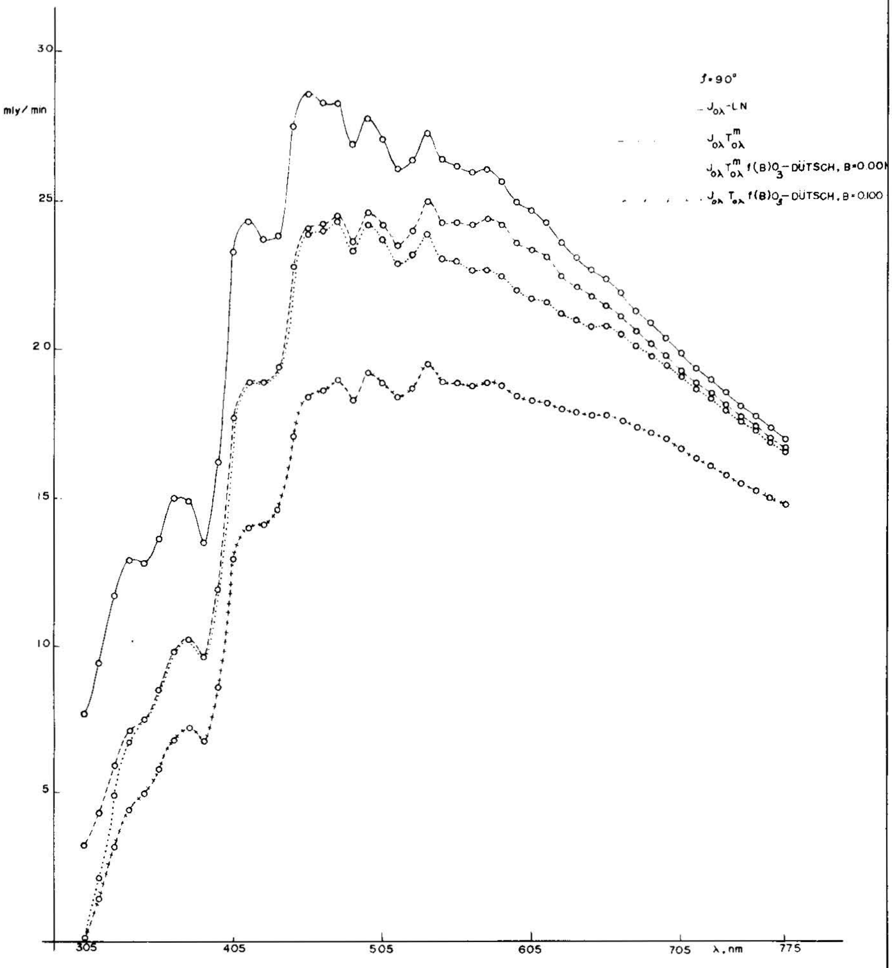

FIGURE 5.3 ATMOSPHERIC ATTENUATION DUE TO AEROSOLS.

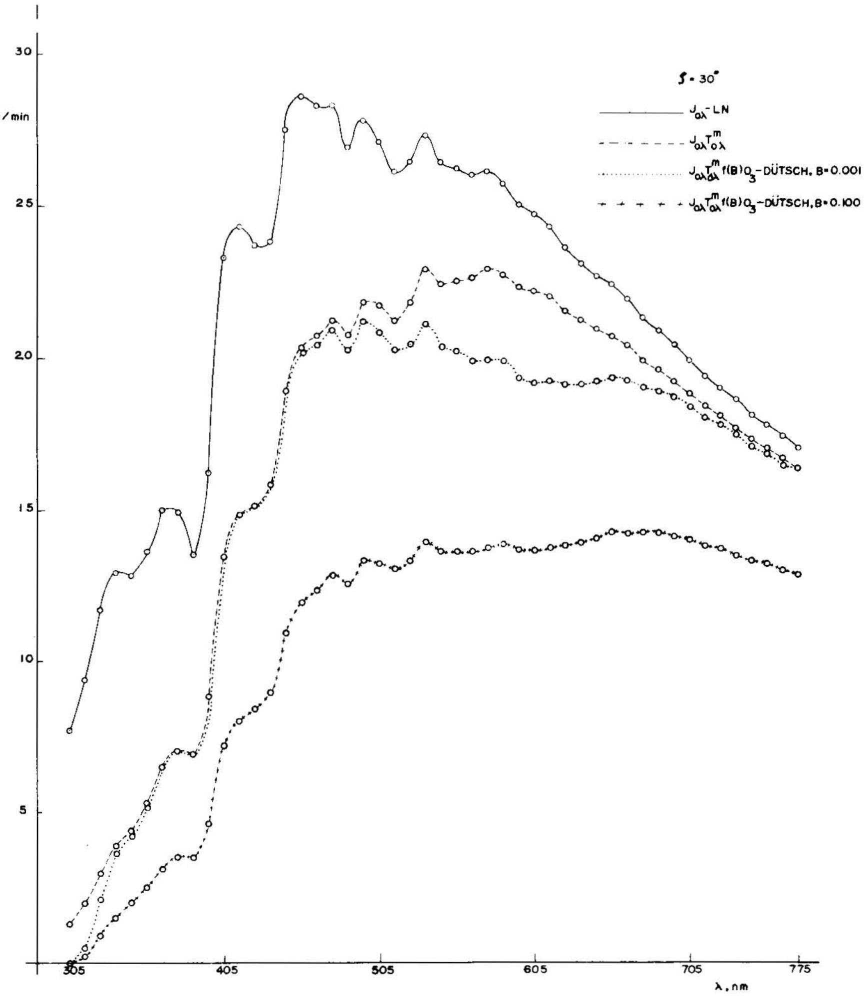

FIGURE 5. 4 EFFECT OF THE ATMOSPHERIC AIR MASS OVER THE AEROSOL ATTENUATION.

The tables and figures show how the different transmission functions attenuate the incoming solar radiation, but Table V.2 shows how the energy is transmitted through the different extinction processes:

TABLE II- TRANSMISSION OF THE ENERGY FOR $\lambda < 700$ NM

Energy Transmitted (%) $\zeta = 90^\circ$	Rayleigh nm	Ozone- Dütsch nm	Ozone- Smithsonian nm	nm	B
40- 60	300-359	300-310			
60- 80	350-430	310-320	300-310	300-510	0.100
80-100	440-770	320-770	310-770	510-770	0.100
				300-770	0.001
$\zeta = 30^\circ$					
	300-310				
20- 40	310-360	300-310	300-310	300-310	0.100
40- 60	360-410	310-320		310-460	0.100
60- 80	410-510	320	310-330	460-770	0.100
80-100	510-770	320-770	330-770	300-770	0.001

As an example, the Rayleigh's extinction for an optical air mass m = 1.0 transfers 40 to 60% of the incoming radiation at 300-350 nm , but for m = 1.995, $\zeta = 30^\circ$, the transmission of the energy of the same order begins at $\lambda < 310$ nm. For an abundance of aerosols of B = 0.001, 80-100% of the energy is transmitted in the whole spectral region; however, for B = 0.100, 60-80% is transmited in the spectral region of 300-510 nm., while for $\zeta = 30^\circ$ with B = 0.100, 20-40% of the energy is transmitted in the region 300-310 nm Finally, there is no practical reduction effect for B = 0.001 due to aerosols as a function of the air mass, since 80-100% of the energy is transmitted in the whole spectral region.

Valko (1971) has recently published a set of tables for computing the turbidity coefficient B for $\lambda < 630$ nm. In Table III we compare the results

TABLE III COMPARISON OF THE RESULTS COMPUTED HERE WITH THOSE OF VALKO (Valko, P., 1971)

		m = 1.0			
		B = 0.001		B = 0.100	
	Solar Constant	0_3-Dütsch	0_3-Smithsonian	0_3-Dütsch	0_3-Smithsonian
Valko	Johnson	633		499	
here computed	Labs and Neckel	583	594	459	468
6% (see page 12 and Kuhn, M., 1971)		618	630	487	496
Difference, mly/min)		13(3.4%)	3(0.5%)	12(2.5%)	3(0.6%)

To explain the small differences found here one has to consider that the Johnson's spectral irradiance curve for actinometric purposes begins at $\lambda = 0.28$ microns; therefore, there is a small contribution of 12 mly/min in the Solar Constant. Another source of discrepancy lies in the ozone abundance, of which we do not know what value Valko has used in his computations. The nearer values calculated with the Smithsonian Ozone absorption coefficient indicate that presumably Valko has used the same coefficients.

2 The Spectral Region, $\lambda > 720$ nm.

Here the absorption of water vapor, CO_2 and O_2 is studied. In this spectral region water vapor is the most important extinction agent.

The results produced here are comparisons between the Mörikofer-Schüepp absorption table for water vapor, CO_2 and O_2 with the Möller's integrated absorption function for water vapor.

Table IV presents a linear correlation obtained between both absorption functions for either the Johnson's or the Nicolet's spectral irradiance curves.

TABLE IV- LINEAR CORRELATION IN TERMS OF B BETWEEN THE MÖRIKOFER-SCHÜEPP (MS) ABSORPTION TABLE FOR WATER, CO_2 AND O_2 AND THE MÖLLER'S (M) INTEGRATED ABSORPTION FUNCTION FOR WATER

Mexico City, 1969	$\bar{B}_x$	$\bar{B}_y$	σ_x	σ_y	a	b	c	N = 80
MS-M	.144	.116	.007	.007	.116	.991	.997	Johnson
MS-M	.144	.123	.007	.007	.123	1.02	.997	Nicolet
Basle, 1958								
MS-M	.127	.106	.007	.007	.106	1.05	.988	Johnson
MS-M	.128	.113	.007	.007	.113	1.07	.990	Nicolet

Note that the average turbidity coefficient B oscillates more if the Möller's formula is used with different Solar Constant distributions than when the absorption spectral table by Mörikofer-Schüepp is used.

From the above data, taking the Mörikofer-Schüepp values as unity, one finds:

	Mexico City		Basle	
	MS	M	MS	M
Johnson	1.0	+ 19%	1.0	+ 12.0%
Nicolet	1.0	+ 15%	1.0	+ 16.0%

which means that the turbidity values calculated with the Möller's formula either with Johnson's (12-19%) or Nicolet's (15-16%) Solar Constant distributions are of the order of 15% higher in average with respect to those calculated with the Mörikofer-Schüepp's table.

In order to study the spectral transmission of the radiant energy for the different spectral windows, Table V.1-5 was prepared from actinometric data, that is, from data for any optical air mass and water content.

To compute this table, the Johnson's Solar Constant distribution was used. The S_j terms correpond to the summation defined in Equation (4), the transmited energies include Rayleigh's scattering and aerosol attenuation for a given B; the computation with the Möller's formula for the same data is also included, as well as the turbidity coefficient obtained by using the Möller's formula.

The results show that there is an absorption of water of the order of 51-58% in average for the region $\lambda > 720$ nm. One sees too that the aerosols together with water have an important reduction effect on the transmission of the radiant energy, as for example in S_4 (0.72-0.80μ) where water absorbs most of the energy. But, in S_{10}($> 3.0\mu$), the absorption decreases to 10-20% approximately. Finally, when comparing results obtained with the spectral table for water absorption by Mörikofer-Schüepp (Equation 10) and Möller's (Equation 9), there is a difference of the order of +24%. If one remembers that the turbidity coefficients from Möller's calculation are 15% higher and assuming that the process is linear, then the difference decreases to 9% between both computations.

We have presented here improvements attained on the computer algorithm for the Actinometric Radiation Field; the process is so flexible that one can test any possible combination of the Solar Constant irradiance curves together with different transmission functions. Then, the algorithm becomes a workable method for any given set of instructions and in this way, the International Commissions are able to recommend the best combinations of Solar Constant distributions with transmission functions.

Table V.I - THE EFFECT OF CHANGING THE OPTICAL AIR AND INCREASING TURBIDITY

Z = 30.0 MR = 1.995 B = 0.100

MICRO	JOLANE	RAYLEI	OZODUT	OZOSMI	DUSTOD	DUSTOS
0.305	7.700	1.330	0.004	0.044	0.001	0.017
0.315	9.400	2.018	0.499	0.788	0.199	0.314
0.325	11.700	3.021	2.106	2.420	0.877	1.007
0.335	12.900	3.900	3.558	3.672	1.539	1.589
0.345	12.800	4.432	4.348	4.432	1.951	1.988
0.355	13.600	5.293	5.281	5.293	2.450	2.456
0.365	15.000	6.461	6.461	6.461	3.093	3.093
0.375	14.900	7.009	7.009	7.009	3.456	3.456
0.385	13.500	6.859	6.859	6.859	3.475	3.475
0.395	16.200	8.804	8.804	8.804	4.577	4.577
0.405	23.300	13.436	13.436	13.436	7.155	7.155
0.415	24.300	14.765	14.765	14.765	8.043	8.043
0.425	23.700	15.082	15.082	15.082	8.392	8.392
0.435	23.800	15.779	15.779	15.779	8.959	8.959
0.445	27.500	18.910	18.842	18.865	10.903	10.916
0.455	28.600	20.317	20.196	20.268	11.897	11.940
0.465	28.300	20.697	20.500	20.599	12.283	12.342
0.475	28.300	21.244	20.942	21.143	12.751	12.874
0.485	26.900	20.672	20.232	20.475	12.509	12.659
0.495	27.800	21.819	21.177	21.508	13.284	13.492
0.505	27.100	21.678	20.790	21.268	13.223	13.526
0.515	26.100	21.240	20.177	20.789	13.002	13.396
0.525	26.400	21.822	20.434	21.180	13.333	13.820
0.535	27.300	22.887	21.077	22.055	13.917	14.564
0.545	26.400	22.419	20.401	21.604	13.625	14.429
0.555	26.200	22.512	20.217	21.564	13.650	14.559
0.565	26.000	22.580	19.895	21.449	13.572	14.633
0.575	26.100	22.889	19.928	21.691	13.731	14.946
0.585	25.700	22.741	19.870	21.602	13.821	15.027
0.595	25.000	22.303	19.418	21.187	13.631	14.872
0.605	24.700	22.202	19.214	20.940	13.606	14.828
0.615	24.300	21.994	19.217	20.868	13.723	14.902
0.625	23.600	21.497	19.145	20.567	13.782	14.806
0.635	23.100	21.165	19.122	20.420	13.872	14.814
0.645	22.700	20.912	19.211	20.912	14.041	15.284
0.655	22.400	20.739	19.328	20.739	14.227	15.266
0.665	21.900	20.370	19.212	20.370	14.240	15.098
0.675	21.300	19.897	18.991	19.897	14.170	14.846
0.685	20.900	19.601	18.889	19.601	14.184	14.719
0.695	20.400	19.203	18.727	19.203	14.149	14.509
0.705	19.900	18.797	18.419	18.797	13.999	14.287
0.715	19.400	18.383	18.078	18.383	13.819	14.053
0.725	19.000	18.058	17.801	18.058	13.683	13.880
0.735	18.600	17.727	17.495	17.727	13.520	13.699
0.745	18.100	17.295	17.089	17.295	13.275	13.435
0.755	17.800	17.049	16.887	17.049	13.184	13.310
0.765	17.400	16.704	16.565	16.704	12.995	13.104
0.775	17.000	16.354	16.315	16.354	12.859	12.890

Table V.2 - ATMOSPHERIC ATTENUATION DUE TO AEROSOLS

Z = 90.0   MR = 1.000   B = 0.001

MICRO	JOLANE	RAYLEI	OZODUT	OZOSMI	DUSTOD	DUSTOS
0.305	7.700	3.194	0.170	0.582	0.169	0.579
0.315	9.400	4.347	2.158	2.713	2.148	2.700
0.325	11.700	5.935	4.953	5.311	4.932	5.287
0.335	12.900	7.083	6.763	6.872	6.735	6.843
0.345	12.800	7.522	7.450	7.522	7.420	7.492
0.355	13.600	8.475	8.464	8.475	8.432	8.442
0.365	15.000	9.834	9.834	9.834	9.798	9.798
0.375	14.900	10.210	10.210	10.210	10.174	10.174
0.385	13.500	9.614	9.614	9.614	9.582	9.582
0.395	16.200	11.934	11.934	11.934	11.895	11.895
0.405	23.300	17.682	17.682	17.682	17.626	17.626
0.415	24.300	18.930	18.930	18.930	18.872	18.872
0.425	23.700	18.895	18.895	18.895	18.840	18.840
0.435	23.800	19.369	19.369	19.369	19.314	19.314
0.445	27.500	22.793	22.752	22.766	22.690	22.704
0.455	28.600	24.095	24.023	24.066	23.959	24.002
0.465	28.300	24.192	24.077	24.135	24.015	24.073
0.475	28.300	24.511	24.335	24.452	24.275	24.391
0.485	26.900	23.573	23.321	23.461	23.265	23.404
0.495	27.800	24.621	24.255	24.445	24.199	24.388
0.505	27.100	24.231	23.729	24.000	23.675	23.946
0.515	26.100	23.539	22.941	23.287	22.890	23.235
0.525	26.400	23.996	23.219	23.640	23.169	23.589
0.535	27.300	24.991	23.980	24.531	23.930	24.480
0.545	26.400	24.323	23.200	23.876	23.153	23.828
0.555	26.200	24.281	23.008	23.764	22.962	23.717
0.565	26.000	24.225	22.736	23.610	22.692	23.564
0.575	26.100	24.438	22.798	23.788	22.756	23.744
0.585	25.700	24.171	22.590	23.557	22.549	23.514
0.595	25.000	23.610	22.026	23.010	21.987	22.969
0.605	24.700	23.415	21.778	22.738	21.741	22.698
0.615	24.300	23.115	21.603	22.514	21.567	22.476
0.625	23.600	22.521	21.251	22.028	21.216	21.992
0.635	23.100	22.109	21.012	21.715	20.978	21.681
0.645	22.700	21.785	20.879	21.785	20.846	21.751
0.655	22.400	21.551	20.803	21.551	20.771	21.518
0.665	21.900	21.119	20.509	21.119	20.478	21.088
0.675	21.300	20.585	20.110	20.585	20.080	20.555
0.685	20.900	20.239	19.866	20.239	19.838	20.210
0.695	20.400	19.791	19.544	19.791	19.516	19.763
0.705	19.900	19.339	19.143	19.339	19.117	19.313
0.715	19.400	18.883	18.726	18.883	18.701	18.858
0.725	19.000	18.522	18.389	18.522	18.365	18.497
0.735	18.600	18.157	18.038	18.157	18.014	18.133
0.745	18.100	17.692	17.586	17.692	17.564	17.669
0.755	17.800	17.420	17.336	17.420	17.315	17.398
0.765	17.400	17.047	16.976	17.047	16.956	17.027
0.775	17.000	16.673	16.653	16.673	16.633	16.653

Table V.3 - ATMOSPHERIC ATTENUATION DUE TO AEROSOLS

Z = 90.0   MR = 1.000   B = 0.100

MICRO	JOLANE	RAYLEI	OZODUT	OZOSMI	DUSTOD	DUSTOS
0.305	7.700	3.194	0.170	0.582	0.105	0.359
0.315	9.400	4.347	2.158	2.713	1.361	1.712
0.325	11.700	5.935	4.953	5.311	3.192	3.422
0.335	12.900	7.083	6.763	6.872	4.445	4.516
0.345	12.800	7.522	7.450	7.522	4.985	5.033
0.355	13.600	8.475	8.464	8.475	5.760	5.767
0.365	15.000	9.834	9.834	9.834	6.798	6.798
0.375	14.900	10.210	10.210	10.210	7.162	7.162
0.385	13.500	9.614	9.614	9.614	6.838	6.838
0.395	16.200	11.934	11.934	11.934	8.597	8.597
0.405	23.300	17.682	17.682	17.682	12.893	12.893
0.415	24.300	18.930	18.930	18.930	13.961	13.961
0.425	23.700	18.895	18.895	18.895	14.085	14.085
0.435	23.800	19.369	19.369	19.369	14.584	14.584
0.445	27.500	22.793	22.752	22.766	17.295	17.306
0.455	28.600	24.095	24.023	24.066	18.426	18.459
0.465	28.300	24.192	24.077	24.135	18.625	18.670
0.475	28.300	24.511	24.335	24.452	18.977	19.069
0.485	26.900	23.573	23.321	23.461	18.326	18.436
0.495	27.800	24.621	24.255	24.445	19.199	19.349
0.505	27.100	24.231	23.729	24.000	18.913	19.129
0.515	26.100	23.539	22.941	23.287	18.405	18.683
0.525	26.400	23.996	23.219	23.640	18.746	19.085
0.535	27.300	24.991	23.980	24.531	19.476	19.924
0.545	26.400	24.323	23.200	23.876	18.950	19.502
0.555	26.200	24.281	23.008	23.764	18.896	19.516
0.565	26.000	24.225	22.736	23.610	18.770	19.491
0.575	26.100	24.438	22.798	23.788	18.915	19.737
0.585	25.700	24.171	22.590	23.557	18.832	19.638
0.595	25.000	23.610	22.026	23.010	18.446	19.270
0.605	24.700	23.415	21.778	22.738	18.319	19.126
0.615	24.300	23.115	21.603	22.514	18.248	19.018
0.625	23.600	22.521	21.251	22.028	18.023	18.682
0.635	23.100	22.109	21.012	21.715	17.890	18.488
0.645	22.700	21.785	20.879	21.785	17.842	18.617
0.655	22.400	21.551	20.803	21.551	17.842	18.483
0.665	21.900	21.119	20.509	21.119	17.650	18.175
0.675	21.300	20.585	20.110	20.585	17.364	17.774
0.685	20.900	20.239	19.866	20.239	17.209	17.531
0.695	20.400	19.791	19.544	19.791	16.982	17.197
0.705	19.900	19.339	19.143	19.339	16.684	16.854
0.715	19.400	18.883	18.726	18.883	16.367	16.504
0.725	19.000	18.522	18.389	18.522	16.117	16.233
0.735	18.600	18.157	18.038	18.157	15.852	15.956
0.745	18.100	17.692	17.586	17.692	15.495	15.588
0.755	17.800	17.420	17.336	17.420	15.313	15.387
0.765	17.400	17.047	16.976	17.047	15.031	15.095
0.775	17.000	16.673	16.653	16.673	14.780	14.798

Table V.4 - THE EFFECT OF CHANGING THE OPTICAL AIR MASS

Z = 30.0   MR = 1.995   B = 0.001

MICRO	JOLANE	RAYLEI	OZODUT	OZOSMI	DUSTOD	DUSTOS
0.305	7.700	1.330	0.004	0.044	0.004	0.044
0.315	9.400	2.018	0.499	0.788	0.494	0.781
0.325	11.700	3.021	2.106	2.420	2.088	2.399
0.335	12.900	3.900	3.558	3.672	3.528	3.642
0.345	12.800	4.432	4.348	4.432	4.313	4.397
0.355	13.600	5.293	5.281	5.293	5.240	5.253
0.365	15.000	6.461	6.461	6.461	6.413	6.413
0.375	14.900	7.009	7.009	7.009	6.960	6.960
0.385	13.500	6.859	6.859	6.859	6.812	6.812
0.395	16.200	8.804	8.804	8.804	8.747	8.747
0.405	23.300	13.436	13.436	13.436	13.352	13.352
0.415	24.300	14.765	14.765	14.765	14.676	14.676
0.425	23.700	15.082	15.082	15.082	14.994	14.994
0.435	23.800	15.779	15.779	15.779	15.690	15.690
0.445	27.500	18.910	18.842	18.865	18.740	18.762
0.455	28.600	20.317	20.196	20.268	20.089	20.161
0.465	28.300	20.697	20.500	20.599	20.396	20.493
0.475	28.300	21.244	20.942	21.143	20.838	21.038
0.485	26.900	20.672	20.232	20.475	20.135	20.377
0.495	27.800	21.819	21.177	21.508	21.078	21.408
0.505	27.100	21.678	20.790	21.268	20.696	21.172
0.515	26.100	21.240	20.177	20.789	20.088	20.697
0.525	26.400	21.822	20.434	21.180	20.347	21.090
0.535	27.300	22.887	21.077	22.055	20.989	21.964
0.545	26.400	22.419	20.401	21.604	20.318	21.517
0.555	26.200	22.512	20.217	21.564	20.138	21.480
0.565	26.000	22.580	19.895	21.449	19.819	21.367
0.575	26.100	22.889	19.928	21.691	19.854	21.611
0.585	25.700	22.741	19.870	21.602	19.798	21.524
0.595	25.000	22.303	19.418	21.187	19.349	21.112
0.605	24.700	22.202	19.214	20.940	19.148	20.868
0.615	24.300	21.994	19.217	20.868	19.153	20.798
0.625	23.600	21.497	19.145	20.567	19.082	20.500
0.635	23.100	21.165	19.122	20.420	19.061	20.355
0.645	22.700	20.912	19.211	20.912	19.151	20.846
0.655	22.400	20.739	19.328	20.739	19.269	20.675
0.665	21.900	20.370	19.212	20.370	19.155	20.309
0.675	21.300	19.897	18.991	19.897	18.936	19.839
0.685	20.900	19.601	18.889	19.601	18.835	19.545
0.695	20.400	19.203	18.727	19.203	18.675	19.149
0.705	19.900	18.797	18.419	18.797	18.368	18.745
0.715	19.400	18.383	18.078	18.383	18.030	18.334
0.725	19.000	18.058	17.801	18.058	17.754	18.010
0.735	18.600	17.727	17.495	17.727	17.450	17.681
0.745	18.100	17.295	17.089	17.295	17.046	17.251
0.755	17.800	17.049	16.887	17.049	16.845	17.007
0.765	17.400	16.704	16.565	16.704	16.525	16.663
0.775	17.000	16.354	16.315	16.354	16.276	16.315

TABLE V.5- SPECTRAL TRANSMISSION OF WATER

		S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_4-S_{10}	Total Absorption	Möller	Difference	%
Transmitted energy without water (mly/min)	1	90	232	212	97	128	115	34	908				
	2	96	244	219	100	131	116	34	940				
	3	93	240	217	99	120	116	34	929				
	4	84	220	203	94	126	113	34	874				
	5	87	227	208	96	127	114	34	893				
Water Transmission (%)	1	93	85	77	36	62	23	15	56				
	2	94	87	80	39	63	25	17	58				
	3	89	80	71	30	58	19	10	51				
	4	91	83	74	33	60	21	12	53				
	5	90	81	72	31	59	19	11	52				
Transmitted energy after water absorption (mly/min)	1	83	198	164	35	79	27	5	591	317	243	74	23
	2	90	213	175	38	83	29	6	634	306	227	79	26
	3	83	192	154	30	76	22	3	560	369	284	85	23
	4	76	182	151	31	75	23	4	542	332	263	69	21
	5	78	184	151	30	75	22	4	544	349	275	74	21

	1	2	3	4	5	
J.S	= 1.150	1.291	1.141	1.057	1.093	ly/min
m	= 1.27	0.88	1.53	0.99	1.07	
w	= 1.91	2.21	2.63	3.18	3.40	cms.
B_M	= 0.113	0.121	0.078	0.191	0.151	

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