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Multiple molecular scattering and albedo action on the solar
spectral irradiance in the region of the UVB (≤ 320 nm) :

a preliminary inventory

by

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FOREWORD

"Multiple molecular scattering and albedo action on the solar spectral irradiance in the region of the UVB (≤ 320 nm) : A preliminary inventory" is dedicated to F.W. Paul Götz and will be published in "Journal of Terrestrial and Atmospheric Physics".

AVANT-PROPOS

"Multiple molecular scattering and albedo action on the solar spectral irradiance in the region of the UVB (≤ 320 nm) : A preliminary inventory" est dédié à F.W. Paul Götz et sera publié dans "Journal of Terrestrial and Atmospheric Physics".

VOORWOORD

"Multiple molecular scattering and albedo action on the solar spectral irradiance in the region of the UVB (≤ 320 nm) : A preliminary inventory" is opgedragen aan F.W. Paul Götz en zal verschijnen in "Journal of Terrestrial and Atmospheric Physics".

VORWORT

"Multiple molecular scattering and albedo action on the solar spectral irradiance in the region of the UVB (≤ 320 nm) : A preliminary inventory" ist F.W. Paul Götz gewidmet und wird in "Journal of Terrestrial and Atmospheric Physics" erscheinen.

MULTIPLE MOLECULAR SCATTERING AND ALBEDO ACTION ON THE SOLAR
SPECTRAL IRRADIANCE IN THE REGION OF THE UVB (≤ 320 nm) :
A PRELIMINARY INVENTORY

by

Marcel NICOLET

Abstract

Solar UVB, a fundamental element in our environment, was measured with cadmium cells by Paul Götz in Arosa more than sixty years ago and described in his book entitled : Das Strahlungsklima von Arosa (1926). Afterwards, in order to ensure uniformity in field experiments, he introduced in his atmospheric measurements a chemical sensor, the Bioclimatic Ultraviolet Dosimeter. This dosimeter, by its cylindrical form, was adapted to an instantaneous measurement of the global UVB radiation at different sites. The global radiation embraces the whole of the group of direct solar irradiances with molecular scattering (sky radiation) and ground reflection (albedo) together with its scattered spectral component.

Numerical results from detailed theoretical calculations aimed at evaluating the various absolute effects associated with height, solar zenith angle and surface albedo have been obtained for the standard atmosphere. The variations with solar zenith angles from 0° to 90° and albedos between 0 and 1 are presented for a spherical terrestrial atmosphere at selected wavelengths between 301 and 325 nm in the UVB region.

Résumé

L'ultraviolet B résultant de l'irradiation solaire est un élément fondamental de notre environnement. Il y a plus de 60 ans, l'UVB fut déjà l'objet de mesures effectuées par Paul Götz à Arosa à l'aide de cellules au cadmium. Elles sont décrites dans son livre intitulé : Das Strahlungsklima von Arosa (1928). Afin d'assurer au mieux l'uniformité des mesures en divers endroits, il adopta parmi l'ensemble de ses instruments le Dosimètre ultraviolet bioclimatique basé sur une méthode chimique. Ce dosimètre, par sa forme cylindrique, était ainsi adapté à la mesure instantanée de l'UVB sous une forme globale dans des sites les plus différents. La radiation globale correspond, en effet, à l'ensemble du groupe constitué de l'irradiance solaire directe à laquelle sont associées la diffusion moléculaire (radiation du ciel) et la réflexion du sol (albedo) avec sa composante multidiffusée.

Des résultats numériques, basés sur des calculs théoriques détaillés, ont conduit, dans le cadre de l'atmosphère standard, à une évaluation des valeurs absolues de la radiation globale en fonction de l'altitude, de la distance zénithale du soleil et de l'albedo. De là, les variations avec l'angle zénithal solaire de 0° à 90° et avec l'albedo de 0 à 1, adaptées à une terre sphérique, sont présentées, dans la région spectrale correspondant à l'UVB, à diverses longueurs d'onde entre 301 et 325 nm.

Samenvatting

UVB straling van de zon, een fundamenteel element in onze omgeving, werd reeds meer dan zestig jaar geleden gemeten in Arosa door Paul Götz en beschreven in zijn boek : Das Strahlungsklima von Arosa (1926). Teneinde de uniformiteit in zijn experimenten op het terrein te verzekeren voerde Götz in zijn atmosferische metingen een chemische sensor in : de "Bioclimatic Ultraviolet Dosimeter". Deze dosimeter was door zijn cylindrische vorm geschikt voor een ogenblikkelijke meting van de globale UVB straling op verschillende plaatsen. De globale straling omvat het geheel van de groep van rechtstreekse zonnestraling met moleculaire verstrooing (hemel straling) en grond reflectie (albedo) samen met zijn verstrooide spectrale component.

Numerieke resultaten van gedetailleerde theoretische berekeningen, bedoeld om de verschillende effecten te bepalen van hoogte, zenith-hoek van de zon en oppervlak-albedo, werden bekomen voor de standaard atmosfeer. De veranderingen te wijten aan variërende zenith-hoeken van de zon gaande van 0° tot 90° en oppervlak-albedo tussen 0 en 1 worden hier getoond voor een sferische aardatmosfeer en geselecteerde golflengtes van 301 tot 325 nm in het UVB gebied.

Zusammenfassung

Die solare Ultraviolettstrahlung UVB, ein wesentliches Element unserer Umgebung, wurde vor mehr als sechzig Jahren durch Paul Götz mit Cadmiumzellen gemessen und in dem Buch : "Das Strahlungsklima von Arosa" (1926) beschrieben. Später, um weitere vergleichbare Experimente durchzuführen, hat Götz in seinen atmosphärischen Messungen ein chemisches Instrument, das bioklimatische Ultraviolettdosimeter, in seine atmosphärischen Messungen eingeführt. Seiner zylindrischen Form wegen war dieses Dosimeter für Messungen der globalen UVB Strahlung an verschiedenen Orten geeignet. Die globale Strahlung ist die Summe von allen direkten solaren Strahlungen zusammen mit der molekularen Streuung (Himmelstrahlung) und mit der Bodenreflexion (Albedo) und auch mit deren gestreuten Spektralkomponenten.

Für die Standardatmosphäre haben ausführliche theoretische Berechnungen die numerische Ergebnisse geliefert, die die absoluten Wirkungen in Abhängigkeit von Höhe, solarem Zenitwinkel und Bodentalbedo beschreiben. Die Änderungen für Zenitwinkel zwischen 0° und 90° und Albedos zwischen 0 und 1 werden für eine kugelförmige Erdatmosphäre und für ausgewählte Wellenlängen zwischen 301 und 325 nm in dem UVB Wellenlängengebiet dargestellt.

1. PREAMBLE

Sixty years ago, the problems of physical bioclimatology were the subject of detailed experimental and observational researches which were developed in a series of institutions organized at high altitudes and at sea level (see Appendix I.A and I.B). One of the various objectives was to detect the biological impact of solar ultraviolet irradiance and particularly of the UVB. The erythemal and bacterial actions were compared and measured by different methods. The cadmium cell and the UV dosimeter were used in Arosa by Götz when I was working with him in 1938 and 1939. The "Bioklimatisches Ultravioletdosimeter der I.G. Farbenindustrie" made by Frankenburger in 1931 was adapted for climatological use thanks to a suggestion of Götz to imitate the solar action on human skin.

After the second World War, the biological impacts of the UV radiation were reevaluated with their possible consequences as an increased risk to man (see Appendix II). It has been asserted that if there were a sufficient decrease in the ozone content, there would be an increase of the strength of the biologically harmful ultraviolet radiation at ground level, and a consequent increase in the incidence of skin cancer. It should be noted that, in fact, ozone is the only atmospheric constituent which prevents the UVC from reaching the ground. In any case, pale skin, formerly so much coveted, gradually lost its allure after the First World War. The changes which followed have led to the present situation where sun-tan has become almost universal throughout our populations. This is why we can now easily recognise feudal systems : either they recommend the veil or they make it compulsory.

Skin cancer was discovered about 1900, by the French dermatologist Dubreuilh, during a study of overexposure of workers to the sun in the vineyards near Bordeaux.

A few years ago, it was found that, in Australia, 25% of the white population (of European origin) of 65 years of age have had several skin cancers, while the aborigines, although less fully clothed, are immune. This is attributed to the difference in the type of melanine pigmentation. When UVB radiation, filtered by the ozone absorption penetrates the epidermis, it encounters cells, the melanocytes, which create melanine, a pigment that provides a natural defence against sunburn. The nitrogen eumelanines (black and brown macromolecular pigments) that give rise to dark skins provide a better screen than the sulphur pheomelanines (reddish-brown macromolecular pigments) that give light-coloured skins. The eumelanines protect the dark-skinned populations, while the pheomelanines, characteristic of the European and particularly Nordic races, provide less protection from sunlight. It is generally believed that skin cancer appears when the UV radiation destroys the DNA in the skin. Hence, if the DNA is not reconstituted or is reconstituted in an abnormal form, a conversion may result which is usually benign, but may be malignant, and which is referred to as skin cancer.

The Climatic Impact Assessment Program was organized in 1971 by the U.S. Department of Transportation. Its purpose was to identify the significant factors of the collective impacts of a fleet of supersonic aircraft (Appendix III, references). Under the chairmanship of Grobecker several conferences were organized from 1972 to 1974. The subject of the biological effects of ultraviolet radiation on man, animal and plants was considered.

Today with the multiplication of ozone holes there is a multiplicity of publications which would require a book of references : Multum in parvo. Nevertheless, we cannot forget that the first ozone measurements made at Halley Bay (75°S) in Antarctica by Stanley Evans in 1956, and also during the International Geophysical Year, that were showed that were peculiarities in the annual variation (MacDowall, 1960a, b); Dobson, 1966, 1968) related to the Antarctic atmospheric circulation.

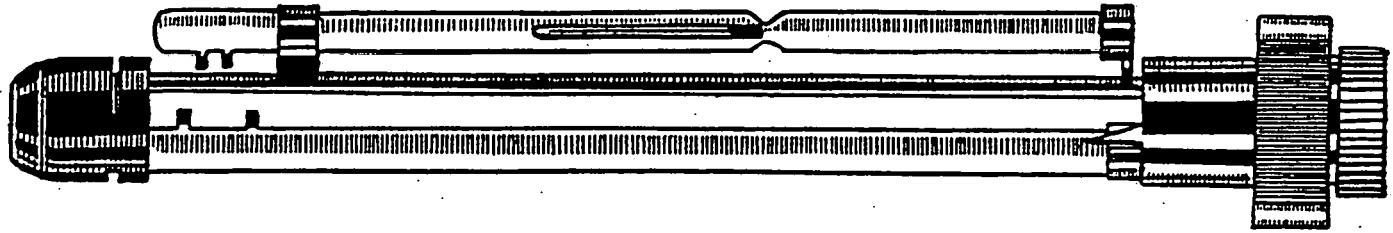
On the other hand, the ozone hole observed for more than a month (March-April 1964) in the North American ozone network indicated (Dütch, 1961) that such a hole was produced near the 50 mbar level by an unusual conjunction of different air streams during several weeks. Now, the decrease every October in Antarctic ozone is commonly known as the Antarctic ozone hole.

2. INTRODUCTION

Simultaneous measurements of the UVB were made in the Spring of 1939 in Switzerland by Götz in Chur (600 m) on a green grassland, by Nicolet in Arosa (1850 m) in a fresh snow environment and by Penndorf on the Weisshorn (2650 m) above the snowy slopes. But the results of these observations were never published (Second World War !) and have been lost.

These measurements were made during a whole day characterized by a perfectly blue sky with bioclimatic ultraviolet dosimeters (Fig. 1a). Such a dosimeter has a spectral sensitivity (Fig. 1b) which is similar to that of biological processes such as bactericidal action or the transformation of ergosterol into vitamin D. The fact that this UVB dosimeter had a cylindrical form provided the possibility of global measurements of the biological effectiveness at three different altitudes with their specific environments. These observations yielded the global radiation of the UVB from the direct solar spectral irradiance, from the diffuse UV due to the molecular scattering, and from the reflected UV particularly important in the fresh snow with an albedo of at least 0.9 at these wavelengths.

I have not forgotten that the numerical values of my measurements in Arosa (Fig. 2) were several times greater than the values obtained at Chur and on the Weisshorn; thus, another evaluation of the effectiveness of the UVB photons for multiple molecular scattering and for various albedo values in the standard atmosphere may permit basic numerical comparisons that will lead to understanding of the variations of the global solar irradiance in this spectral region.



Bioklimatisches Ultravioletdosimeter der I. G. Farbenindustrie.

Fig. 1a. The bioclimatic ultraviolet dosimeter used in Arosa in 1938-39.

See K. Büttner, Physikalisches Bioklimatologie, Appendix IB.

The details of the physical aspects of measurements of the physiologically active ultraviolet radiations by means of the photochemical formation of triphenylmethane dyestuff from leuco compounds are given in an article published by Edith Weyde and W. Frankenburger (1931).

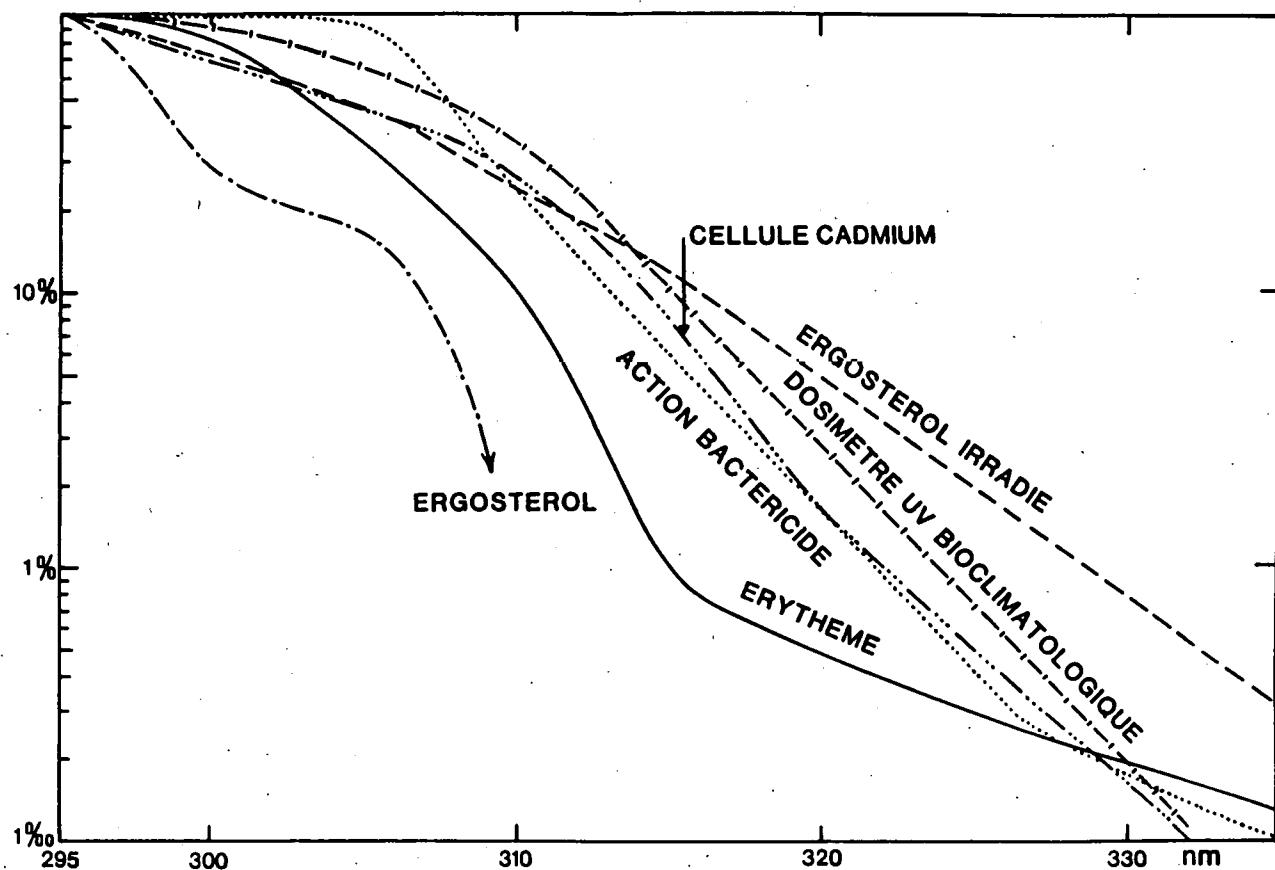


Fig. 1b. Relative effectiveness in the UVB for various wavelengths.
Erythema production, bacterial action, ..., cadmium cell, UV
Bioclimatic Dosimeter. See Büttner, Appendix IB.



Fig. 2. Panoramic view of Arosa in the Spring. Measurements with an UVB bioclimatic dosimeter were made on a snowy slope fronting the sun near the Tchuggen Hotel, the large building almost at the centre of this figure (X).

3. RADIATION FIELD IN THE UVB REGION

3.1. General and numerical analyses

The effect due to the terrestrial albedo and of atmospheric multiple scattering has been the subject of many studies (see references, for example, in Meier et al., 1982; Nicolet et al., 1982; Anderson, 1983; Henderson-Sellers and Wilson, 1983; Scotto et al., 1988; Stammes et al., 1988; Henriksen et al., 1989; Anderson and Lloyd, 1990).

3.2. Transmittance and its amplification factor

The transmittance T_r is the primary source function S_o to be considered for a certain wavelength λ , for a particular height z , and for a specific solar zenith angle x ,

$$\begin{aligned} T_{r\lambda}(x, z) &= S_o(A=0, MS=0, x, z) \\ &= q_D/q_\infty = \exp [-\tau_\lambda(z)f(x)] \end{aligned} \quad (1)$$

when no albedo effect, $A = 0$, and no molecular scattering effect, $MS = 0$ are taken into account. The transmittance corresponds to the ratio of the direct attenuated solar flux q_D = number of photons $\text{cm}^{-2}\text{s}^{-1}$ to the number of photons $\text{cm}^{-2}\text{s}^{-1}$ q_∞ at the top of the earth's atmosphere; $\tau_\lambda(z, x)$ is the optical depth at wavelength λ for the solar zenith angle x at altitude z . Thus, a relative air mass M at an altitude z for a particular zenith angle x is defined by the ratio $M(z, x)/M(z, x=0)$.

The aeronomic processes which control the behaviour of an atmospheric molecule depend not only on the direct solar spectral irradiance, but also on the atmospheric scattered radiation and on the albedo. The scattering reaches its maximum effect near the ground-sea

level, $z_0 = 0$ km, where the molecular number density is maximum. Thus, there is a first basic enhanced source function S , between 90 km and 0 km,

$$S(A=0, MS, x, z)_{z_0=0\text{km}} = (q_D + q_{MS})/q_\infty \quad (2)$$

where q_{MS} is the first enhanced number of photons $\text{cm}^{-2} \text{s}^{-1}$ resulting from molecular scattering; its basic value is reached at sea-level, $z_0 = 0$ km. Thus, the atmospheric transmittance is increased by a factor x ,

$$S(A = 0, MS, x, z) = x \text{Tr} \quad (2a)$$

The ratio of the relations (1) and (2) can be considered as the first basic amplification ratio R_b

$$\begin{aligned} R_b &= S(A=0, MS=0, x, z)/S_0(A=0, MS=0, x, z) \\ &= (q_D + q_{MS})/q_D = 1 + [q_{MS}/q_D]_{z_0=0\text{km}} \end{aligned} \quad (3)$$

The introduction of an albedo $0 \leq A \leq 1$ leads to the addition of a direct reflectance effect and also of the subsequent molecular scattering of the radiation resulting from the albedo. Thus, the global basic enhanced source function, $A > 0$, $MS > 0$, at $z_0 = 0$ km, is

$$S(A, MS, x, z)_{z_0=0\text{km}} = [q_D + q_A + q_{MS} + q_{MSA}]/q_\infty \quad (4)$$

where q_A and q_{MSA} are the number of photons $\text{cm}^{-2} \text{s}^{-1}$ resulting from the direct albedo and from the scattered albedo, respectively.

The simultaneous introduction of the molecular scattering and of albedo effects on a molecule near sea level yields a global basic amplification ratio R_G , (1) and (4),

$$R_G = S(A, MS, x, z) / S_o(A=0, MS=0, x, z) \Big|_{z_o=0 \text{ km}}$$

$$= 1 + [q_A + q_{MS} + q_{MSA}] / q_D \quad (5)$$

with $z_o = 0 \text{ km}$

When the ground level is not at $z_o = 0 \text{ km}$, but at 1, 2, 3 or 4 km, the global amplification ratio depends on the relative importance of the molecular scattering (decreasing with height) and of the albedo between 0 and 1. This aspect will not be discussed here.

3.3. Numerical results

In order to give some idea of the general behaviour of the various values of the global basic amplification ratio R_G in the spectral ultraviolet region, Table 1 provides (for the ultraviolet region from 400 nm to 301 nm) an example of numerical values at 5 km (troposphere) and 50 km (stratopause) for an overhead sun, $x = 0$. In the spectral region where the ozone absorption does not play an important role, $\lambda > 325 \text{ nm}$, the basic amplification ratio at 50 km is about 1.5 ± 0.1 for $A = 0$, and increases to 1.6 ± 0.1 , 1.7 ± 0.1 , 1.9 ± 0.2 , 2.25 ± 0.20 and 2.60 ± 0.30 for $A = 0.1$, 0.25 , 0.50 , 0.75 and 1.0 , respectively.

Thus, the additional effect of molecular scattering for an overhead sun at the stratopause level is to increase the number of photons available for photochemical processes, between 300 and 400 nm, by about 50% and the maximum increase of the albedo effect, $A = 1$, is not less than a factor 2.5.

In the troposphere (5 km, Table 1) the maximum relative increase in the number of photons available for photolytic actions resulting from the molecular scattering occurs in the spectral region of ozone absorption; it is of the order of 2.5 between 301 and 330 nm.

TABLE 1.- Global basic amplification ratio at 5 and 50 km for an overhead sun, $x = 0$ and for albedos $0 \leq A \leq 1$ at various wavelengths between $\lambda = 301$ and $\lambda = 400$ nm.

(nm)	A = 0	A = 0.10	A = 0.25	A = 0.50	A = 0.75	A = 1.0
301	2.48 1.01	2.60 1.01	2.79 1.01	3.17 1.01	3.75 1.01	4.16 1.01
305	2.60 1.03	2.76 1.03	3.01 1.03	3.51 1.03	4.13 1.04	4.92 1.04
310	2.65 1.08	2.86 1.09	3.14 1.10	3.74 1.12	4.50 1.14	5.48 1.17
315	2.65 1.20	2.86 1.22	3.20 1.25	3.87 1.31	4.73 1.39	5.85 1.49
320	2.61 1.35	2.82 1.39	3.18 1.44	3.90 1.56	4.81 1.71	6.01 1.91
325	2.54 1.48	2.76 1.52	3.13 1.62	3.86 1.79	4.79 2.02	6.01 2.31
330	2.45 1.54	2.68 1.61	3.05 1.72	3.78 1.93	4.70 2.20	5.90 2.55
335	2.37 1.59	2.59 1.66	2.96 1.79	3.69 2.03	4.60 2.34	5.77 2.74
340	2.28 1.60	2.50 1.68	2.87 1.81	3.59 2.08	4.48 2.41	5.61 2.82
345	2.20 1.58	2.42 1.67	2.79 1.81	3.49 2.08	4.36 2.42	5.45 2.84
350	2.13 1.56	2.35 1.65	2.71 1.80	3.40 2.08	4.25 2.43	5.30 2.86
375	1.84 1.48	2.05 1.58	2.40 1.75	3.05 2.07	3.81 2.45	4.71 2.90
400	1.64 1.40	1.86 1.52	2.19 1.71	2.81 2.05	3.51 2.45	4.31 2.90

Between 300 and 350 nm, the maximum additional effect of the albedo, A-1, occurs near 320-325 nm and corresponds to a global increase of a factor of 6 for the number of photons available for such photochemical processes as the photodissociation of nitrogen dioxide.

4. AERONOMIC PARAMETERS IN THE UVB REGION

Complete analysis of the amplification of the number of photons available for photochemical processes in the atmosphere which results from molecular scattering and from albedo effects requires simultaneous determination for all solar zenith angles, $\chi = 0$ to 90° , for all heights z , for all albedos, $A = 0$ to 1, and for ground levels from the sea level $z_0 = 0$ km to $z = 4$ km. For that purpose, the determination of the atmospheric optical depth τ_{AT} and an equivalent atmospheric optical depth $\tau(MS,A)$ portray the effects.

The atmospheric optical depth $\tau_{AT}(MS=0,A=0)$ that corresponds to the atmospheric transmittance Tr (eq.1) can be compared (eq. 2a) with an equivalent optical depth $\tau(MS,A=0)$ associated with an amplification factor x when only the molecular scattering MS is involved and the albedo does not play a role, $A = 0$:

$$x Tr_\lambda = e^{-\tau_\lambda(z,MS) f(x)} \quad (6)$$

With an albedo effect, there is an increase in the number of photons $\text{cm}^{-2} \text{s}^{-1}$ (eq. 4) available for various molecular processes which corresponds to an equivalent reduced optical depth $\tau_\lambda(z,MS,A)$ that depends on augmentation of the amplification factor x ,

$$x Tr_\lambda = e^{-\tau_\lambda(z,MS,A)f(x)} \quad (7)$$

Figures 3, 4, 5, 6 and 7 illustrate the numerical results obtained at ground level $z_0 = 0$ km for the following wavelengths : 301, 305, 310,

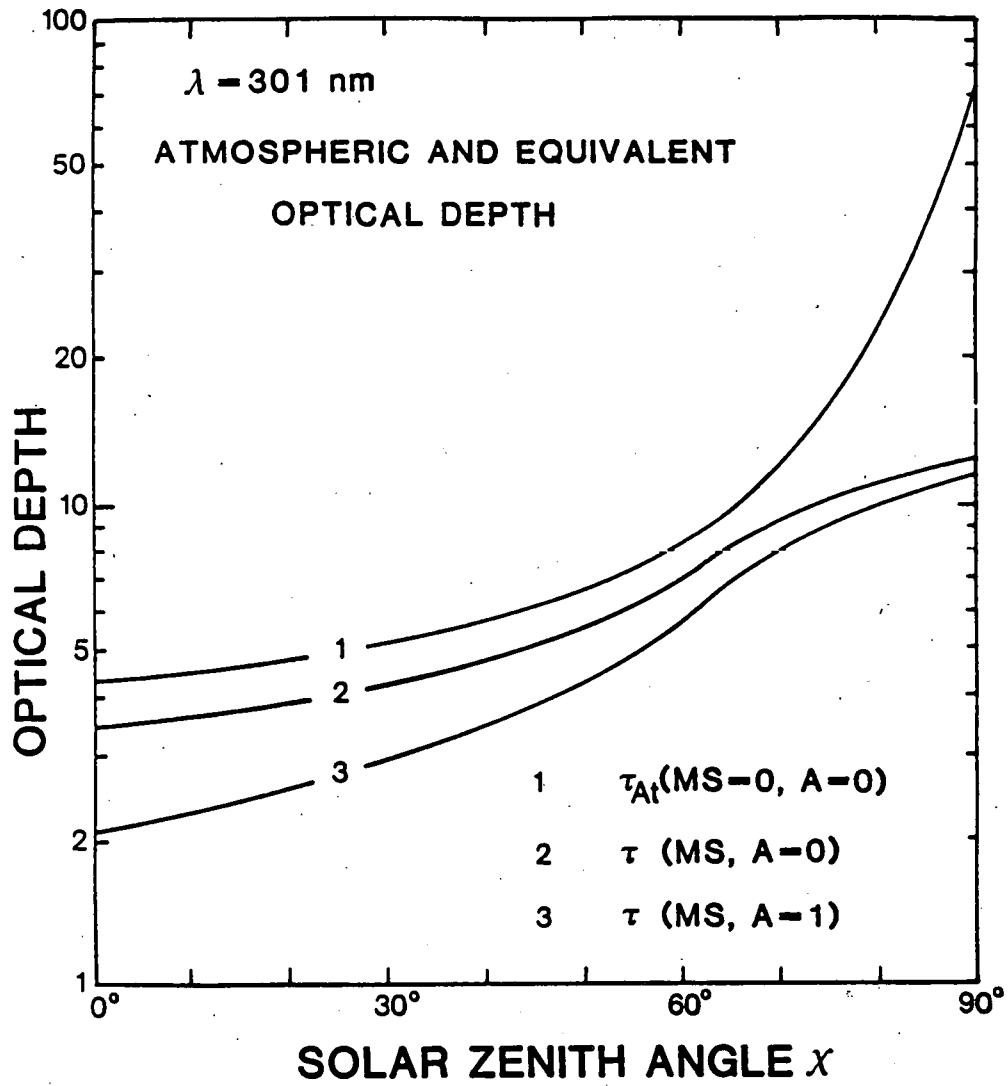


Fig. 3. Optical depths at 301 nm for solar zenith angles from $x = 0$ to $x = 90^\circ$ and height $z_o = 0 \text{ km}$.

- (1) Atmospheric optical depth $\tau_{\text{AT}} (\text{MS} = 0, \text{A} = 0)$ corresponding to the atmospheric transmittance;
- (2) Equivalent optical depth $\tau (\text{MS}, \text{A}=0)$ with the molecular scattering effect;
- (3) Equivalent optical depth $\tau (\text{MS}, \text{A}=1)$ with the addition of the maximum albedo $\text{A} = 1$.

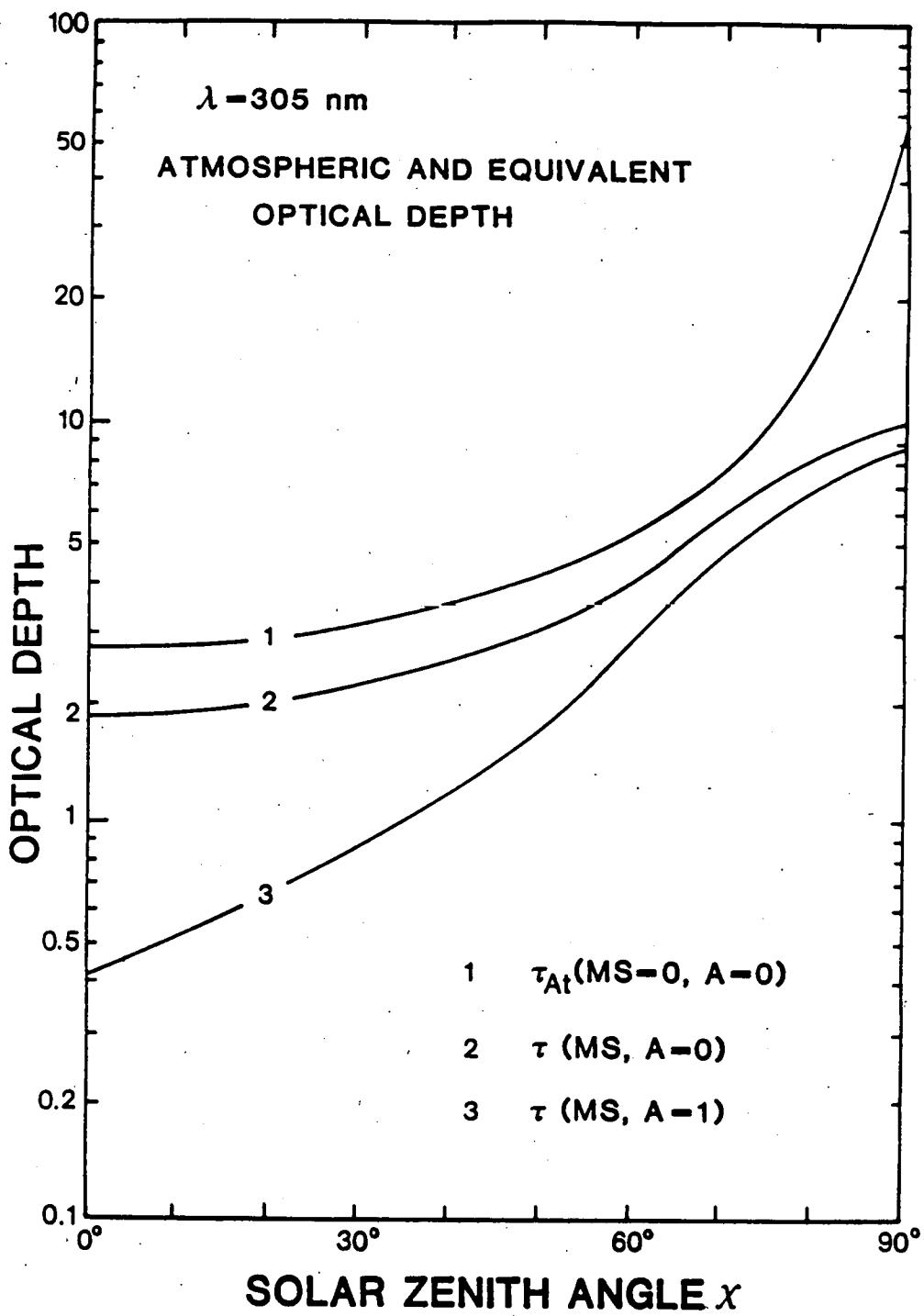


Fig. 4. As in Fig. 3, but for $\lambda = 305 \text{ nm}$.

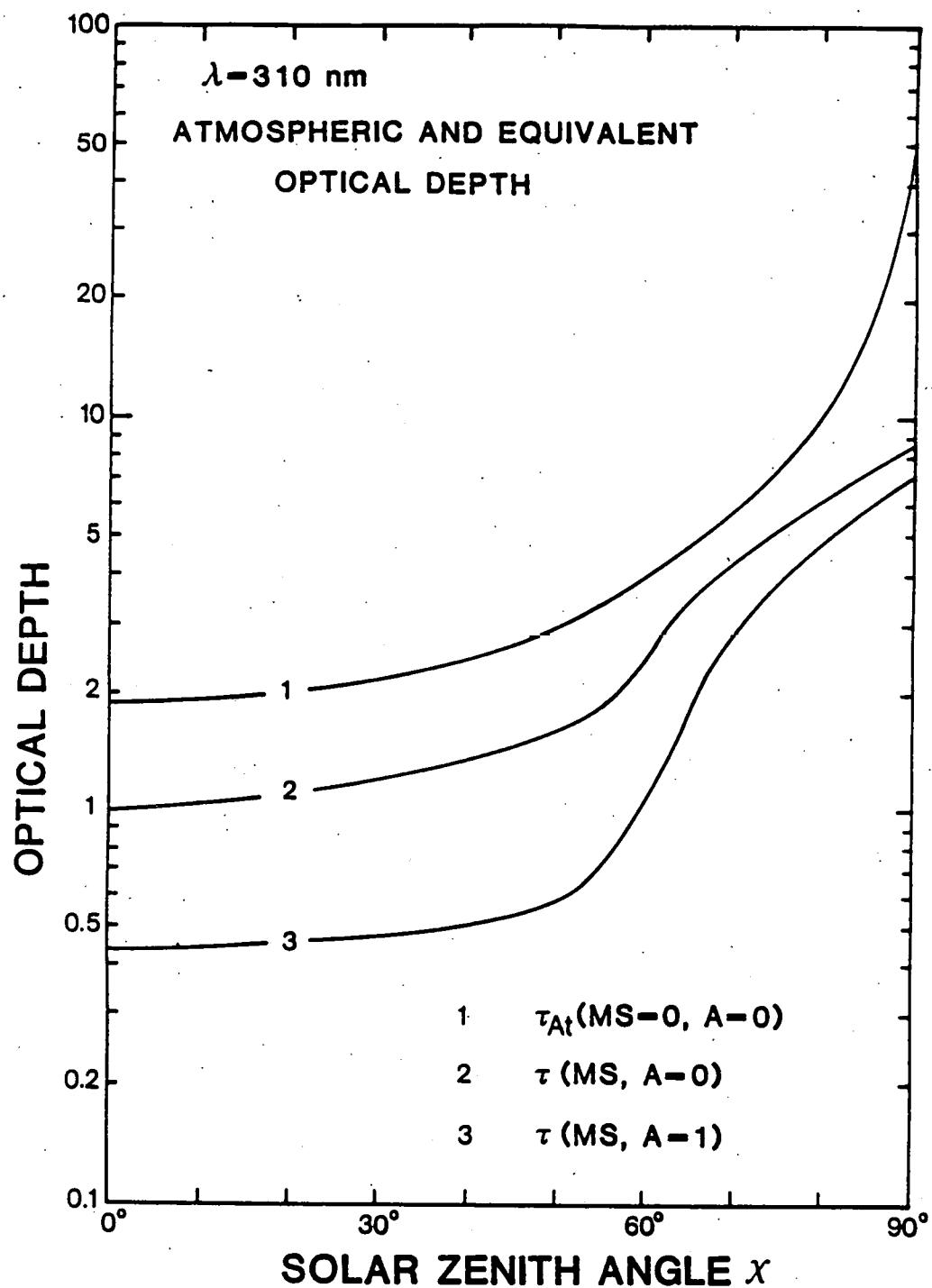


Fig. 5. As in Fig. 3 and 4, but for $\lambda = 310 \text{ nm}$.

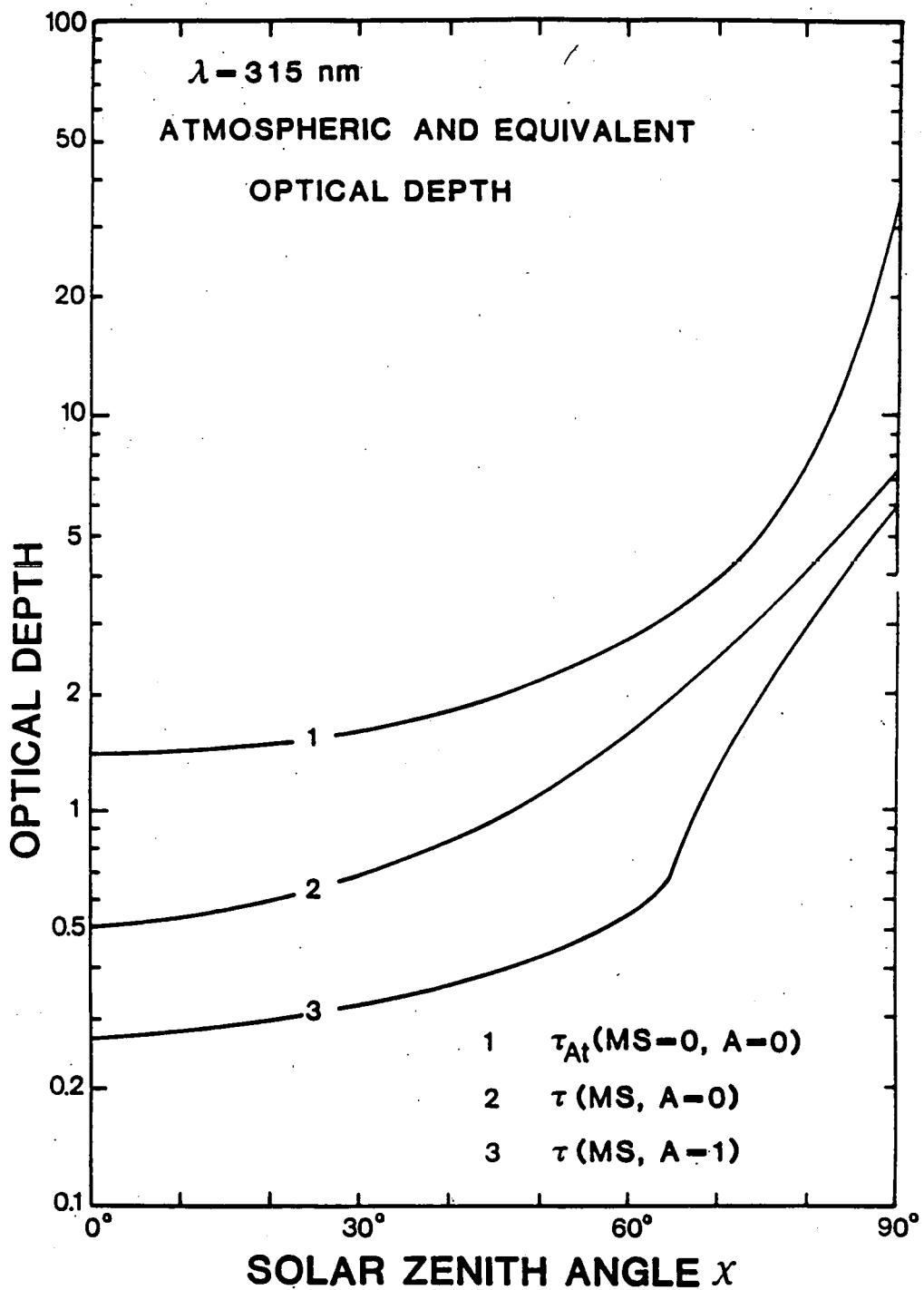


Fig. 6. As in Fig. 3, 4 and 5, but for $\lambda = 315 \text{ nm}$.

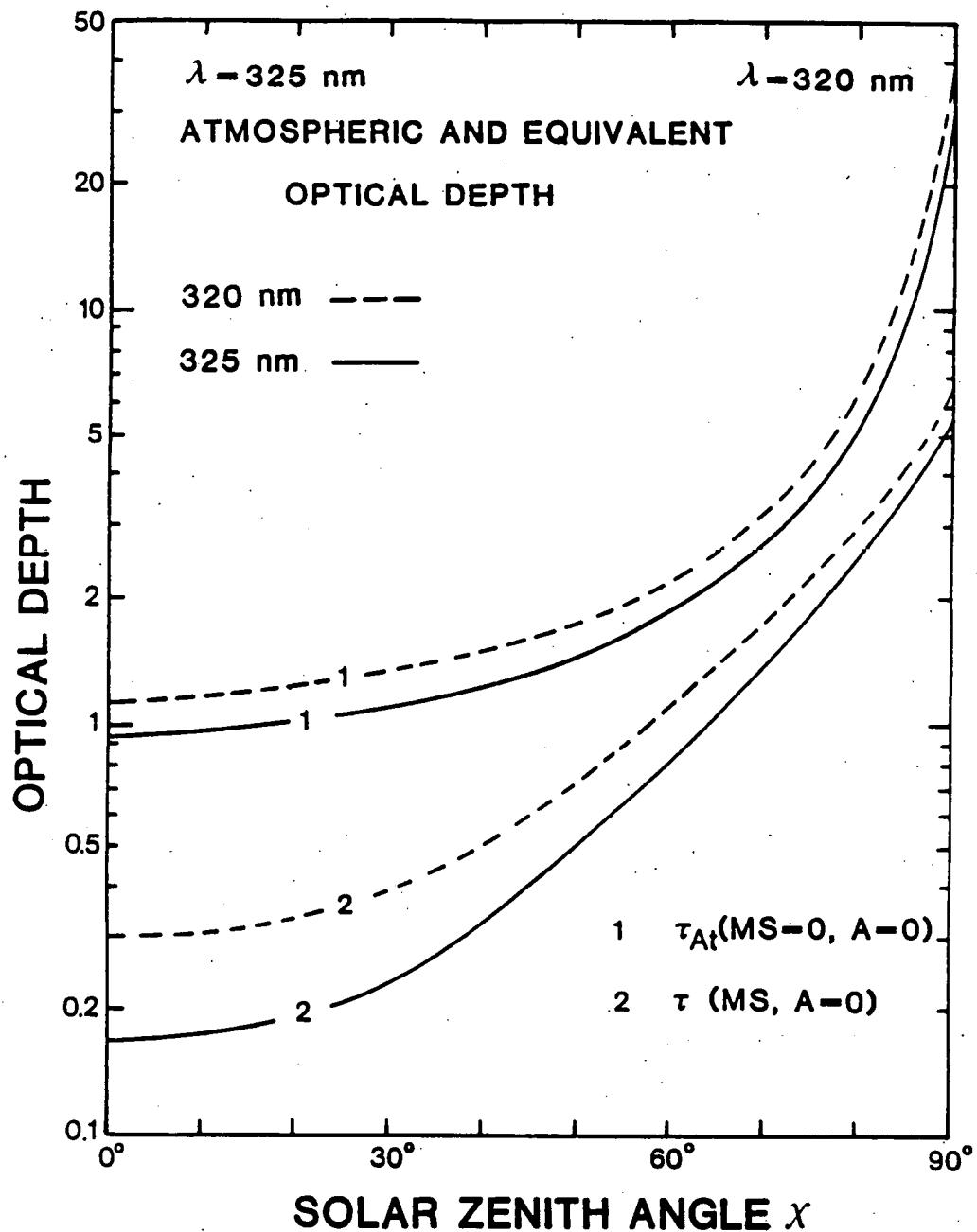


Fig. 7. Atmospheric and equivalent optical depths ($A = 0$) for 320 and 325 nm as in Fig. 3 to 6.

315, 320 and 325 nm, respectively. Figure 8 is an example showing the variation of the atmospheric optical depth for the wavelength 305 nm at various heights (0, 5, 10 and 15 km) for all solar zenith angles $\chi = 0^\circ$ to 90° . The variation of the atmospheric mass $M(\chi)$ is also indicated when $M(\chi=0) = 1$.

At 301 nm, the atmospheric optical depth, which has a value between 4 and 5 for an overhead sun, reaches a value of the order of 80 when the sun arrives at the horizon. But the molecular scattering reduces r_{AT} to about 3.5 at $\chi = 0$ and to a relatively low equivalent value of the order of 10 at $\chi = 90^\circ$; the amplification factor x of the transmittance, which is of the order of 2 from an overhead sun, reaches the extreme value of the order of 10^{31} when the sun is at the horizon.

The introduction of the additional effect due to the various albedos (Fig. 3 to 6, $A = 1$) shows that the highest increase takes place at low solar zenith angles and that the augmentation is negligible at the horizon.

In short, the atmospheric transmittance Tr adopted here at $z_0 = 0$ km, for $\chi = 0$, corresponds to an optical depth r_{AT} of about 4.2. This transmittance with the molecular scattering effect yields an equivalent transmittance amplified by about 2.4; it corresponds to an equivalent optical depth of the order of $0.8 r_{AT}$. For $A > 0$, $A = 0.1, 0.25, 0.50, 0.75$ and 1.0 the amplification factors are approximately 3, 4, 5, 7 and 9 corresponding to equivalent depths of the order of $0.75 r_{AT}, 0.65 r_{AT}, 0.60 r_{AT}, 0.55 r_A$ and $0.5 r_A$, respectively. At $\chi = 90^\circ$; the atmospheric transmittance that corresponds to an optical depth r_{AT} of the order of 85 is effectively reduced to a corresponding equivalent optical depth of about $0.15 r_{AT}$ for an amplification factor by molecular scattering that is not less than 10^{31} .

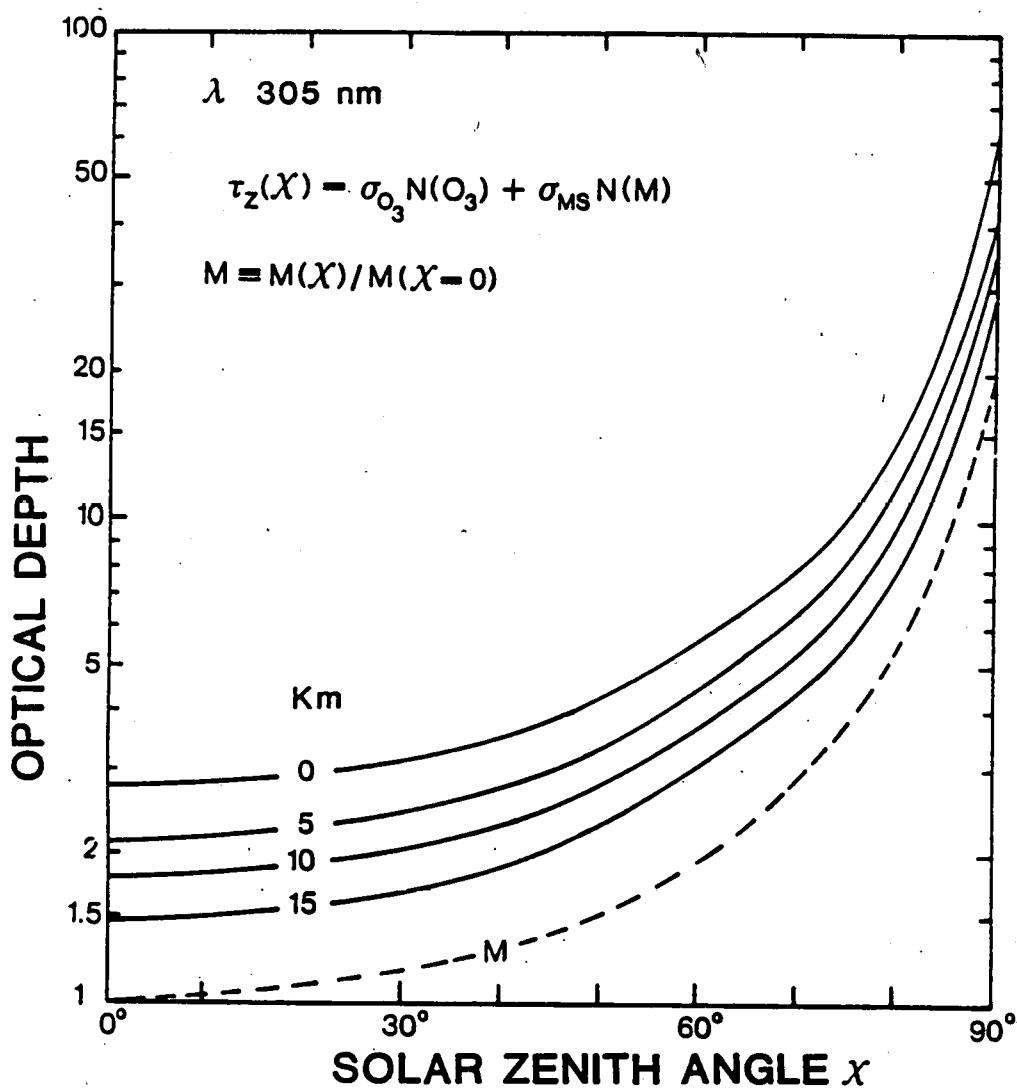


Fig. 8. Optical depths at 305 nm for various heights $z = 0, 5, 10$ and 15 km and the variation of the air mass M with solar zenith angle.

Finally, Table 2 provides for $\lambda = 301$ nm a comparison of the atmospheric transmittance for solar zenith angles from $x = 0^\circ$ to $x = 90^\circ$ at $z_o = 0$ km with its amplification factor x that results from molecular scattering and from the maximum albedo.

At 305 nm (Fig. 4), the optical depth τ_{AT} is about 2.7 at $z_o = 0$ km for an overhead sun. With molecular scattering the equivalent optical depth corresponds to $\tau_{MS} = 0.7 \tau_{AT}$ and with the additional effect of the albedo $A = 0.1$, $A = 0.25$, $A = 0.50$, $A = 0.75$ and $A = 1.0$, the equivalent optical depths are $0.6 \tau_{AT}$, $0.5 \tau_{AT}$, $0.4 \tau_{AT}$, $0.3 \tau_{AT}$ and $0.2 \tau_{AT}$, respectively. At the horizon, $x = 90^\circ$, the atmospheric optical depth τ_{AT} that is of the order of 60 is reduced by the molecular scattering effect to an equivalent optical depth $\tau_{MS} = 0.15 \tau_{AT}$.

Table 3, like Table 2, compares the atmospheric transmittances for different solar zenith angles with their various amplification factors. With such values, $x = 10$ at $x = 0$ and $x = 8 \times 10^{22}$ at $x = 90^\circ$, the global basic enhanced source functions attain about 0.65 and 2×10^{-4} .

At 310 nm (Fig. 5), the differences in the variation of the atmospheric and equivalent optical depths with solar zenith angle are obvious. For an overhead sun, the atmospheric optical depth τ_{AT} that is about 2 decreases to 1 by the effect of molecular scattering ($\tau_{MS,A=0}$) and is reduced to less than $\tau_{(MS,A=1)} = 0.5$ for an albedo $A = 1$. At solar zenith angles greater than 60° , the albedo effect is reduced, and at $x = 90^\circ$ the atmospheric optical depth of the order of 50 reaches an equivalent value of the order of 8 that corresponds to less than $0.2 \tau_A$. The amplification factor x of the transmittance may reach a value of 10 (Table 4) for low solar zenith angles. On the other hand, the global basic enhanced source function S reaches 7×10^{-4} at $x = 90^\circ$ where the source function is only of order 10^{-21} ; the amplification factor x cannot be less than 10^{17} .

TABLE 2.- Amplification factors x of the atmospheric transmittance Tr at 301 nm by molecular scattering (x_{MS}) showing the additional effect of the albedo $A = 1$, ($x_{MS,A=1}$) for solar zenith angles from $\chi = 0^\circ$ to 90° at height $z_0 = 0$ km.

x	Tr	x_{MS}	$x_{MS,A=1}$
0°	1.4×10^{-2}	2.4	9.2
30°	7.5×10^{-3}	2.5	9.2
50°	1.4×10^{-3}	3.1	10.
65°	5.0×10^{-5}	6.5	21.
75°	1.4×10^{-7}	2.9×10^2	1.6×10^3
80°	1.7×10^{-10}	1.3×10^5	4.7×10^5
83°	1.0×10^{-13}	1.5×10^8	5.4×10^8
87°	2.8×10^{-22}	3.1×10^{16}	1.1×10^{17}
90°	3.1×10^{-37}	1.4×10^{31}	4.9×10^{31}

TABLE 3.- Amplification factors x of the atmospheric transmittance Tr at 305 nm due to molecular scattering (x_{MS}), with the additional effect of the albedo, $A = 1$, ($x_{MS,A=1}$) for solar zenith angles from $\chi = 0^\circ$ to 90° at height $z_0 = 0$ km.

x	Tr	x_{MS}	$x_{MS,A=1}$
0°	6.5×10^{-2}	2.4	10
30°	4.3×10^{-2}	2.6	10
50	1.5×10^{-3}	3.0	10
65°	1.7×10^{-3}	4.8	16
75°	3.7×10^{-5}	25	87
80°	4.5×10^{-7}	6.8×10^2	2.5×10^3
83°	3.2×10^{-9}	5.7×10^4	2.1×10^5
87°	2.9×10^{-15}	3.1×10^{10}	1.1×10^{11}
90°	1.8×10^{-27}	2.2×10^{22}	8.3×10^{22}

TABLE 4.- Amplification factors x of the atmospheric transmittance Tr at 310 nm due to molecular scattering (x_{MS}) with the additional effect of the albedo, $A = 1$, ($x_{MS,A=1}$) for solar zenith angles from $\chi = 0^\circ$ to 90° at height $z_0 = 0$ km.

x	Tr	x_{MS}	$x_{MS,A=1}$
0°	0.15	2.4	10
30°	0.10	2.6	10
50°	5.3×10^{-2}	3.0	10
65°	1.2×10^{-2}	4.3	14
75°	8.4×10^{-4}	12	41
80°	3.7×10^{-5}	76	2.8×10^2
83°	1.0×10^{-6}	1.2×10^3	4.4×10^3
87°	2.7×10^{-7}	1.8×10^7	6.6×10^7
90°	9.7×10^{-22}	2.0×10^{17}	7.3×10^{17}

With increasing wavelength (see Fig. 6 and 7, for $\lambda = 315$, 320 and 325 nm) the atmospheric optical depth decreases. At $x = 0$, τ_{AT} is 1.4 , 1.1 and 0.95 at 315 , 320 and 325 nm, respectively, and with the effect of molecular scattering the equivalent optical depths become $0.4 \tau_A$, $0.2 \tau_A$ and $0.1 \tau_A$. Such equivalent optical depths correspond to an amplification factor of the atmospheric transmittance of the order of 2.35 ± 0.05 at $x = 0$ and lead to an amplification factor of 10 for low solar zenith angles. Thus, such photolytic processes as the photo-dissociation of O_3 and NO_2 may be subject to an increase of a factor of 10 near sea level for low solar zenith angles under perfectly clear atmospheric conditions.

In conclusion, from 325 to 310 nm, the atmospheric optical depth, at $z_0 = 0$ km for an overhead sun $x = 0$, varies approximately by a factor of 4 , i.e. from about 1 to 4 for standard atmospheric conditions. The introduction of molecular scattering of the spectral solar radiation corresponds to an increase in the UVB radiation available for photolytic processes by an amplification factor of about 2.5 when the albedo (ground reflectance) is 0 . When the albedo is of order 1 , the effects of the direct reflectance and the associated scattered radiation yield an amplification factor of the order of 10 .

There is, as expected, a relative augmentation of the molecular scattering with solar zenith angle, and with an associated decrease of the albedo effect. At the horizon, the direct albedo effect is without significance. But the direct and reflected molecular scattering effects grow considerably with the corresponding decline of the direct solar irradiance. When, between 325 and 300 nm, the atmospheric optical depth at $x = 90^\circ$ increases from about 30 to 90 , the corresponding amplification varies from about 10^{12} to 10^{32} , an increase of a factor of 10^{20} in the global amplification ratio, identical to an equivalent optical depth only of the order of 0.15 of the atmospheric optical depth τ_A .

5. THE SOLAR SPECTRAL IRRADIANCE BETWEEN 300 AND 325 NM

In the 300-325 nm spectral region, the structure of the solar spectrum is complicated by the distribution of the absorption lines; it exhibits variations of a factor of 5 in the detailed irradiances. Thirteen years ago (see Simon, 1978), the precision of the various results obtained with a resolution of a few Angströms was of the order of $\pm 10\%$. Today, the numerical values for intervals of 1 nm still indicate disparity in the observational results; the precision is of the order of $\pm 15\%$.

In the region between 300 and 325 nm, (Table V), there are three main types of detailed measurements of the solar spectral irradiances. The last results were obtained in 1985 in Spacelab 2 by Van Hoosier et al. (1987): the Solar Ultraviolet Spectral Irradiance Monitor (SUSIM). These results, obtained with a 0.15 nm band pass, are listed at each 0.05 nm. Satellite data were also obtained in 1978 by Heath (1980); for them the spectral irradiances are listed at intervals of 0.2 nm for an instrumental resolution of about 1 nm. The observational data of Arvesen et al. (1969) obtained by aircraft at about 12 km were published for intervals of 0.4 nm between 340 and 300 nm. These observed irradiances must be adjusted (see Nicolet, 1975, 1989) to a slightly different value of the total irradiance and, at the same time, to a difference in wavelength which rises to 0.4 nm at wavelengths less than 340 nm (see e.g. Broadfoot, 1972, Simon, 1978). It is important to remember that the results depend on the atmospheric transmittance which was determined at 11.5 km; if it is still 0.9 at 400 nm for a vertical column, it decreases to 0.8 at 330 nm and it is only 0.45 at 310 nm. According to Arvesen et al. (1969) the maximum instrumental error of 3% at 400 nm increases to 4% at 330 nm and reaches at least 7% at 310 nm.

The numerical values listed in Table 5 are illustrated in accompanying figures (Fig. 9, 10, 11 and 12). A comparison between the results of Mentall and Heath between 300 and 330 nm is shown in Fig. 9

TABLE 5.- Solar spectral irradiances averages in 1 nm intervals, $q_x = 10^{14}$ photons $\text{cm}^{-2} \text{s}^{-1}$, deduced from Spacelab 2 measurements and compared with results deduced from observations of Heath, of Arvesen et al. (1969), of Mentall et al. (1981, 1985) and of Mentall and Williams (1988).

Wavelength Interval (nm)	q SUSIM 1 nm	Ratio SUSIM ARVESEN	Ratio SUSIM HEATH	Ratio SUSIM MENTALL I	Ratio SUSIM MENTALL II
300 - 301	0.603	0.73	0.92	1.01	0.85
1 2	0.793	0.86	1.14	1.06	0.92
2 3	0.812	1.00	1.06	1.16	1.09
3 4	1.04	1.19	1.06	1.04	0.88
4 5	0.985	1.15	1.04	1.11	0.93
5 6	0.990	1.04	1.07	1.02	0.86
6 7	1.00	1.04	1.11	1.09	1.05
7 8	1.12	1.07	1.12	1.05	1.00
8 9	1.10	1.23	1.13	1.03	0.94
309 - 310	0.851	1.06	1.03	1.03	0.92
310 1	1.13	1.07	1.10	1.15	1.15
1 2	1.30	1.15	1.13	1.02	0.91
2 3	1.17	1.04	1.09	1.13	1.02
3 4	1.26	1.10	1.11	1.13	0.97
4 5	1.14	1.00	1.05	1.06	0.93
5 6	1.12	1.04	1.11	1.07	0.88
6 7	1.10	0.96	1.04	1.19	1.09
7 8	1.45	1.13	1.19	1.11	0.97
8 9	1.16	0.98	1.05	1.21	1.04
9 - 320	1.19	0.98	1.01	1.08	0.94
320 1	1.47	1.06	1.15	1.09	0.95
1 2	1.19	0.98	1.03	1.09	0.99
2 3	1.25	1.08	1.02	1.01	0.91
3 4	1.22	1.20	1.09	1.15	1.05
324 - 325	1.42	1.30	1.11	1.09	0.99

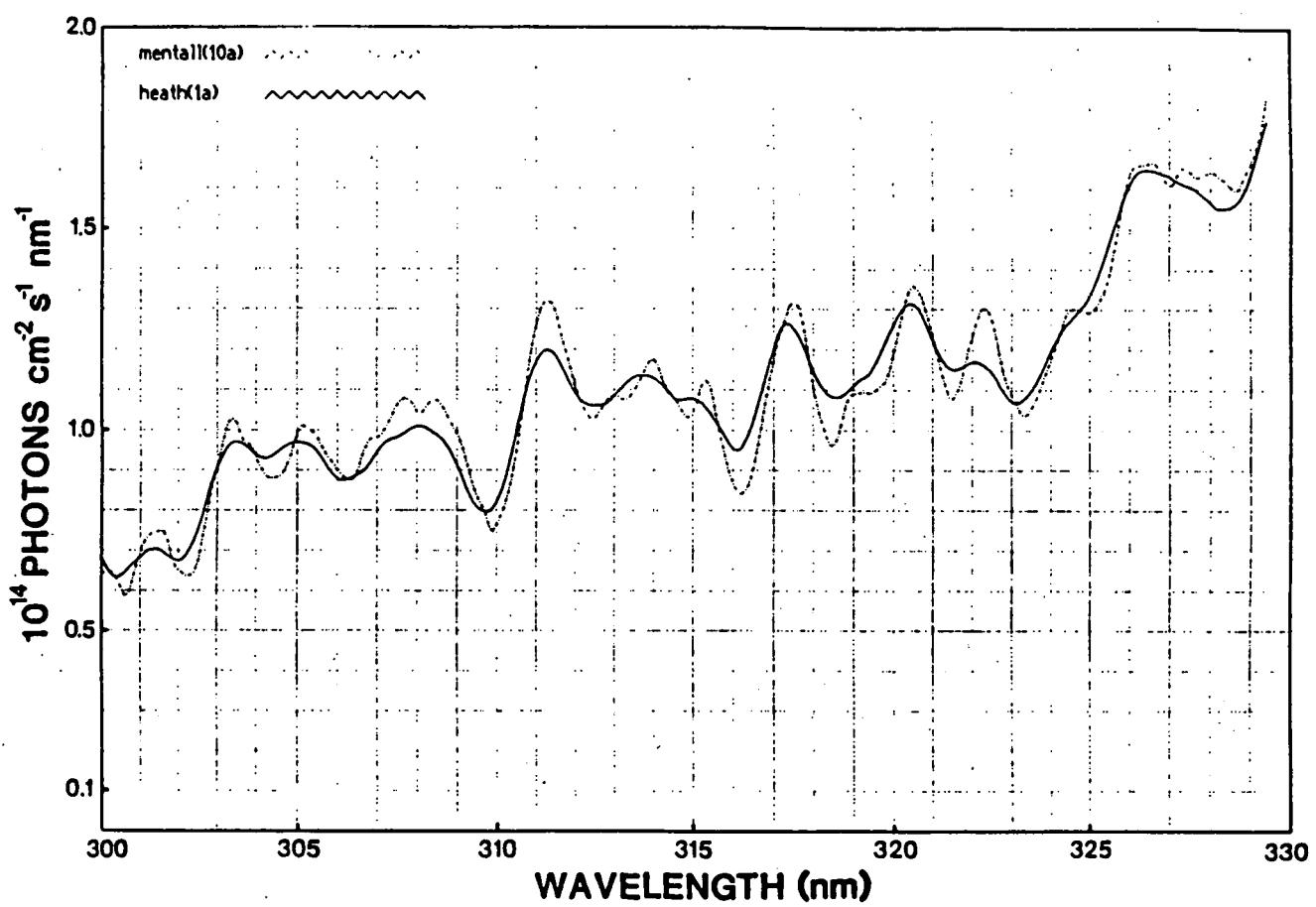


Fig. 9. Comparison of solar spectral irradiances between 300 and 330 nm obtained by Mentall et al. (1981) and by Heath (1980).

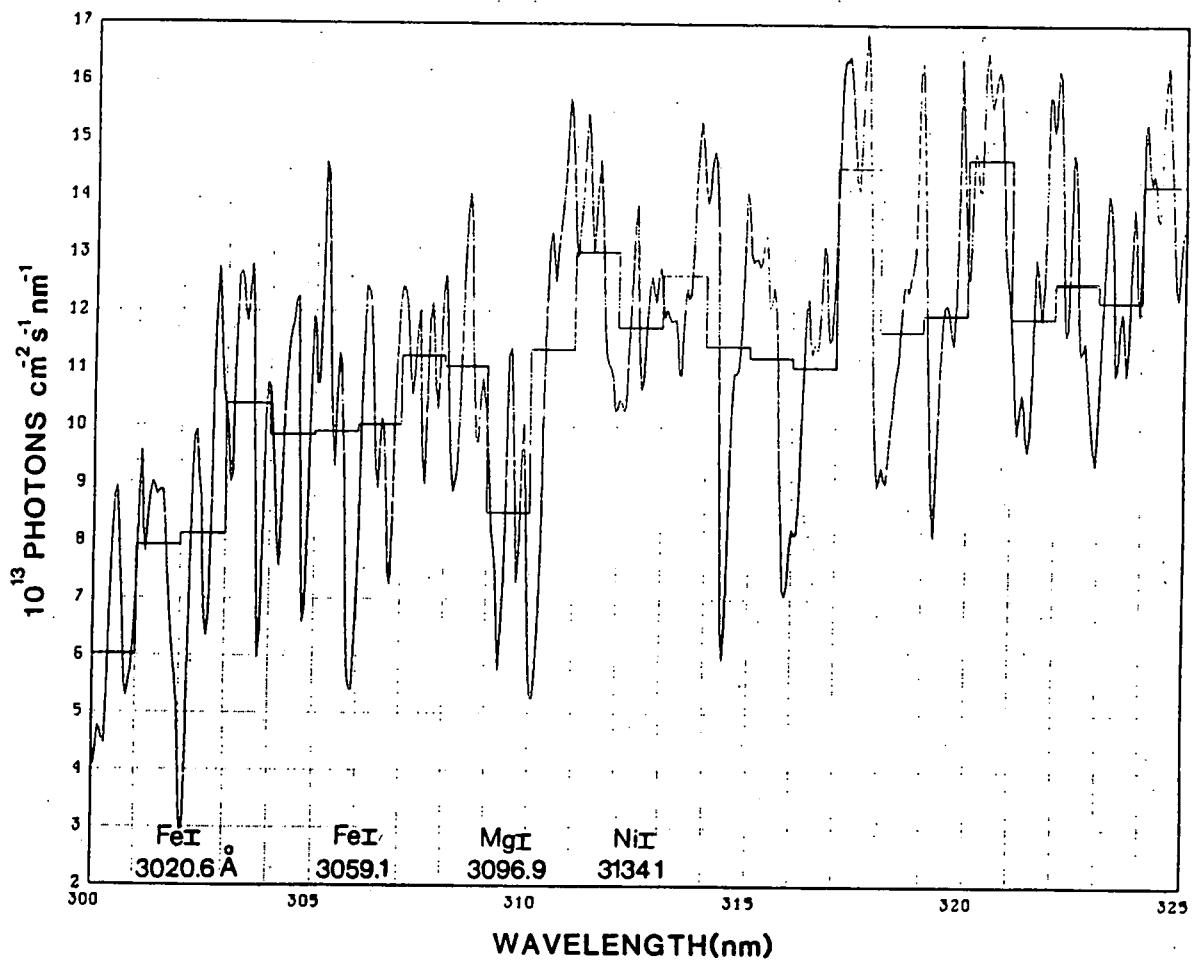


Fig. 10. Solar spectral irradiances between 300 and 325 nm observed by VanHoosier et al. (1988).

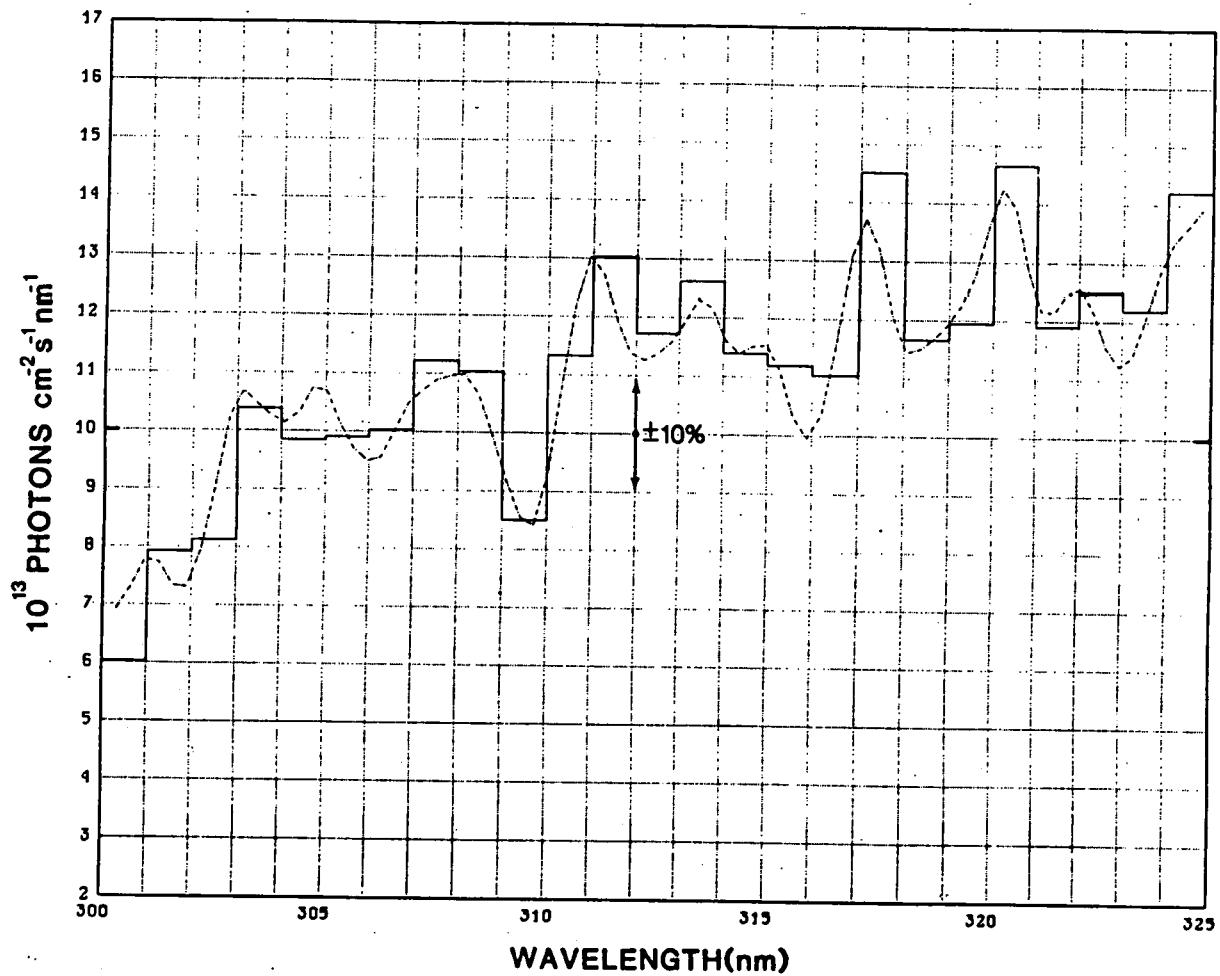


Fig. 11. Solar spectral irradiances between 300 and 325 nm from SUSIM (VanHoosier *et al.*, 1988) Spacelab 2 for 1 nm intervals compared with the irradiances of Spacelab 1 (Labs *et al.*, 1987).

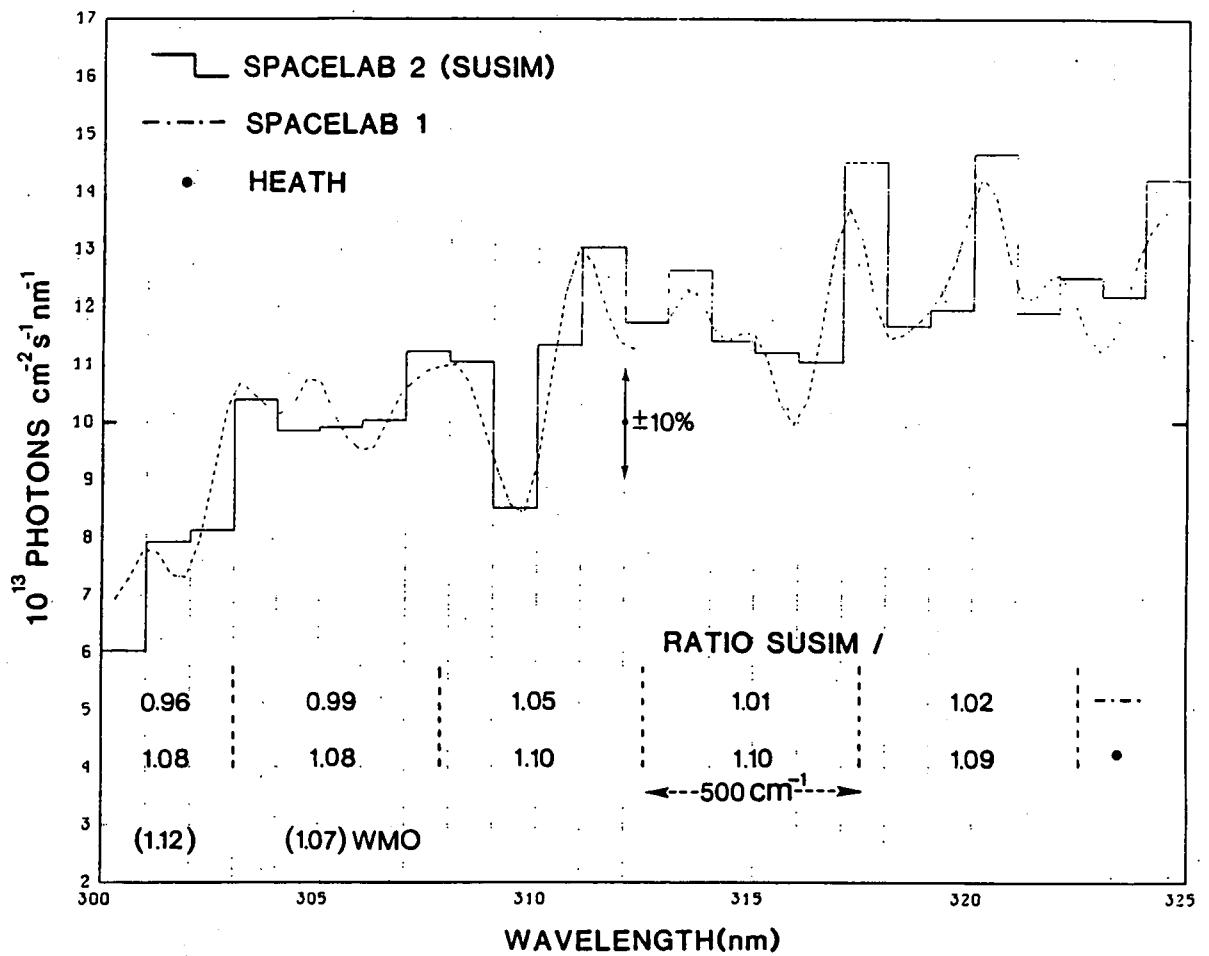


Fig. 12. For 500 cm^{-1} intervals, comparison with the World Meteorological Organization data (1986).

where the differences reach their highest values in the maxima and minima of the solar irradiances because their spectral resolutions are different. The spectral structure given by the Solar Ultraviolet Spectral Irradiance (SUSIM) with its resolution of 0.15 nm with values averaged over 1 nm intervals is illustrated in Fig. 10. When these results are compared with the irradiances of Spacelab 1 (Labs et al. 1987) corresponding to 3 measurements for 1 nm intervals (Fig. 11), the maxima and minima occur in the same spectral regions. For 500 cm^{-1} intervals as shown in Fig. 12, the agreement is good to within $\pm 5\%$. But the values deduced from the measurements made by Heath show that they are $9 \pm 1\%$ lower than the SUSIM data. On the other hand, the values adopted in the WMO report (1986) seem also to be lower than the SUSIM data. Thus, even if the SUSIM irradiances were to be recommended as the reference data, this important photolytic region will require special analysis before adoption of an absolute reference; it is noteworthy that the ozone absorption cross section decreases by more than one order of magnitude with increasing wavelength and depends on the temperature in the spectral region of the UVB. Fig. 13a and b based on experimental data of Bass and Paur (1985) illustrate the variation of the O_3 absorption cross section for temperatures between 200 K and 300 K. Thus, discrepancies may persist between various determinations of the solar radiation field in the troposphere and stratosphere.

6. CONCLUSIONS

This study has compared, in the spectral UVB region, the various components of the solar radiation field in order to explain the large differences obtained in April 1939 by Götz in Chur (green meadows), Nicolet in Arosa (adequate location in the snow) and Penndorf on the Weisshorn (above the ski slopes). From simultaneous measurements made at the same solar zenith angles, it was found that the values obtained in Arosa were between 5 and 10 times those obtained in Chur and on the

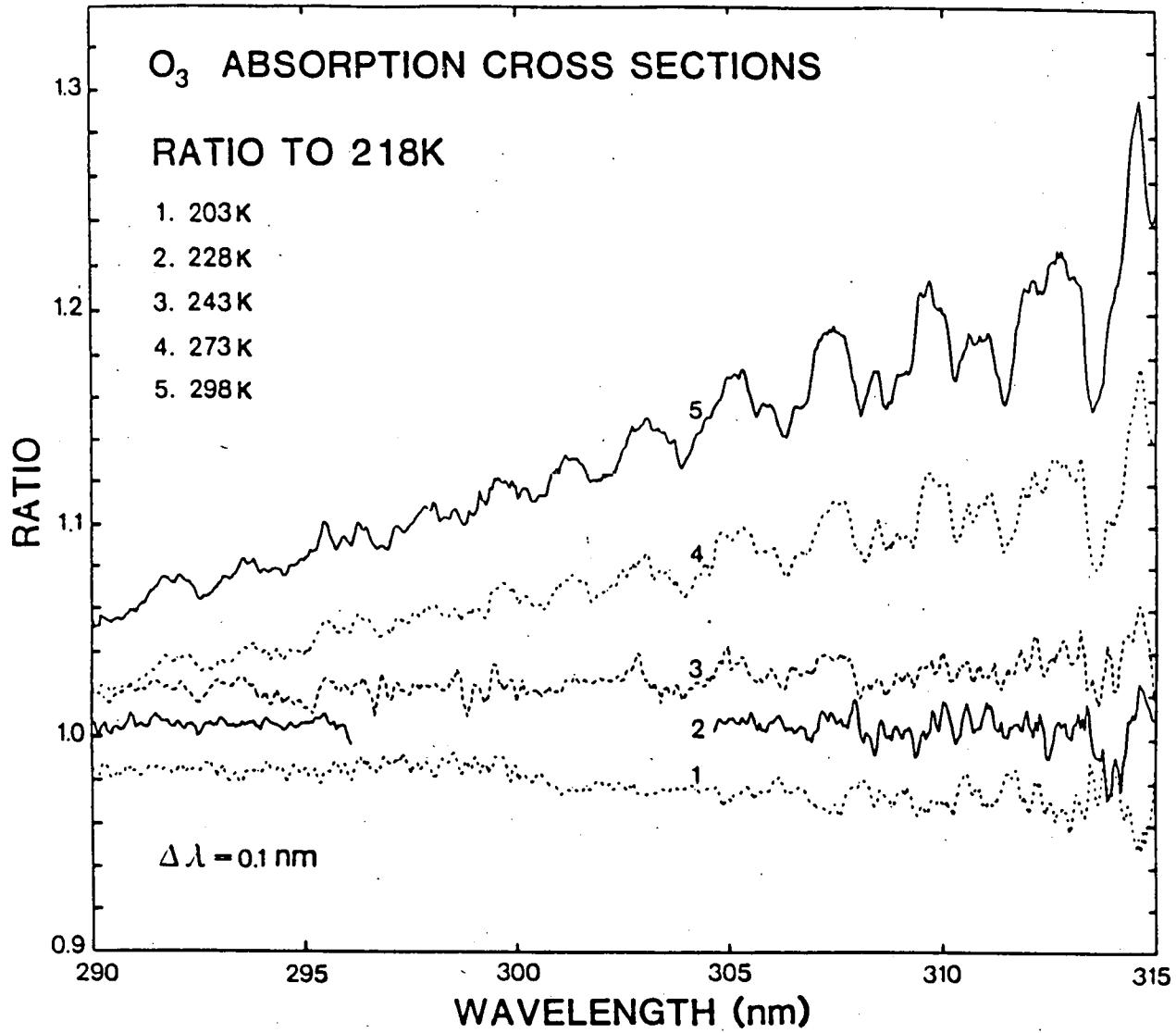


Fig. 13a. Ratios of O₃ absorption cross sections between 290 and 315 nm based on the experimental results of Bass and Paur (1982).

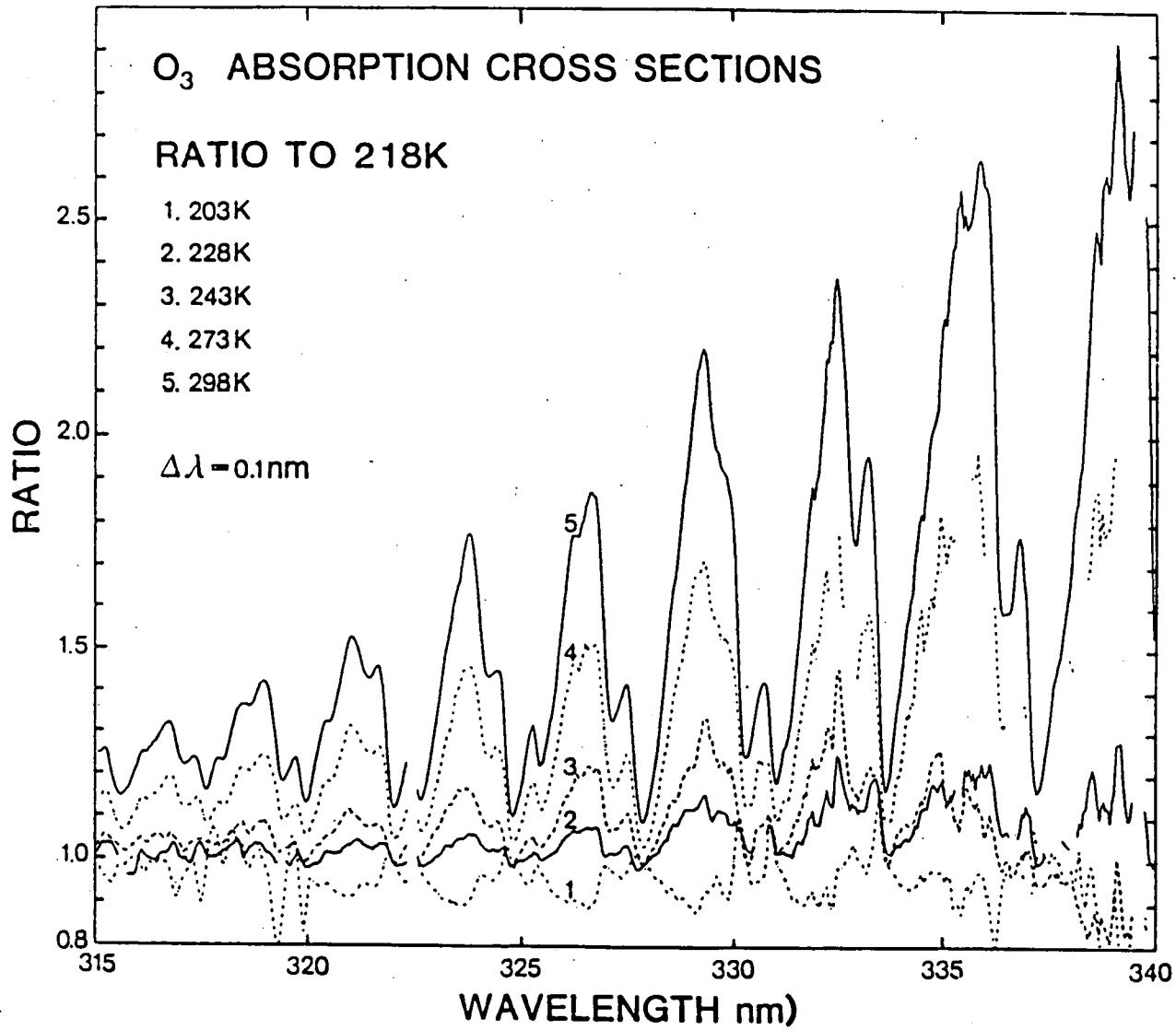


Fig. 13b. As in Fig. 13a but between 315 and 340 nm.

Weisshorn. Such results are explained (see Fig. 14) by a maximum of reflectivity of the snow covering the slope facing the relatively low sun and its associated multiply scattered radiation in addition to the multiple molecular scattering of the atmosphere.

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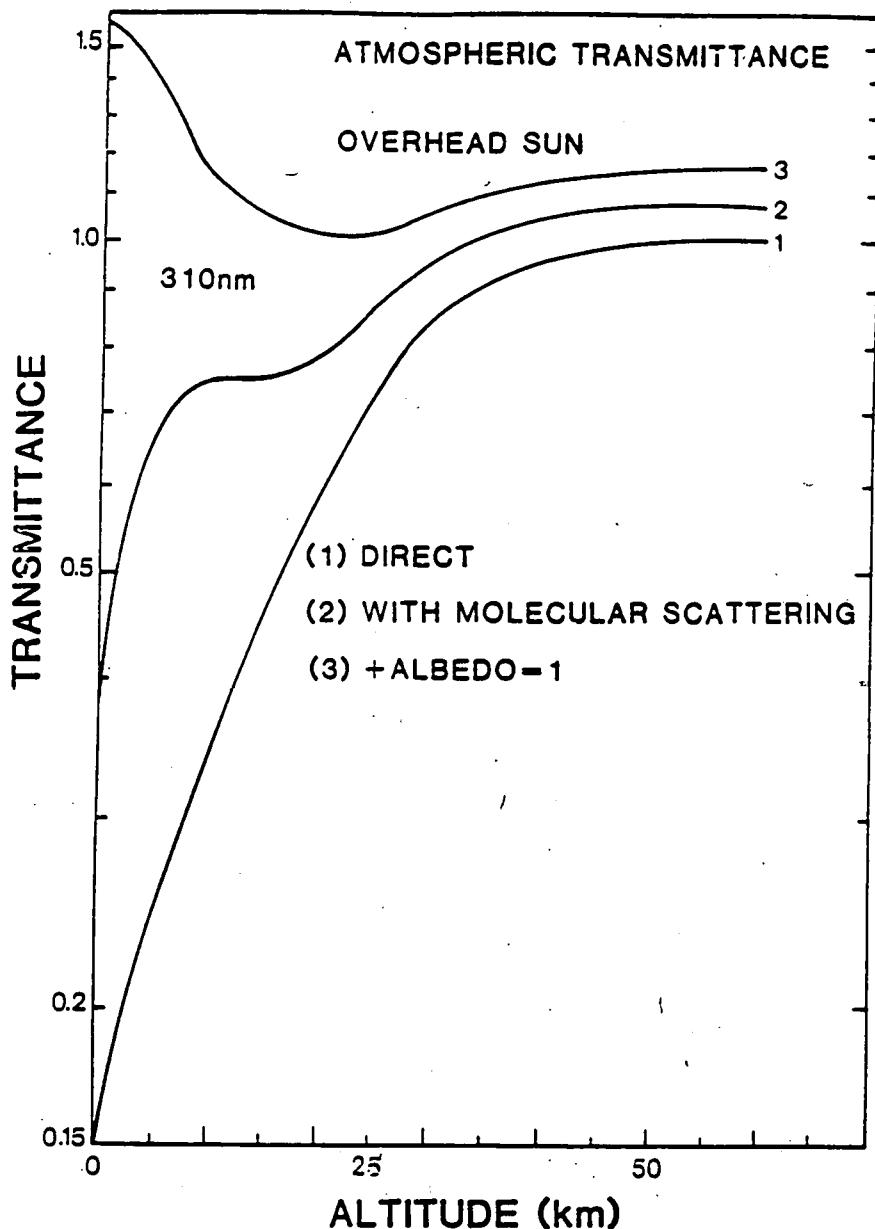


Fig. 14. Atmospheric and equivalent transmittance at $\lambda = 310$ nm for an overhead sun from 0 to 60 km in the standard atmosphere. The transmittance is illustrated by

- (1) the simultaneous absorption effect of molecular scattering and of ozone;
- (2) an increase of the transmittance due to the addition of the multiple molecular scattering with a maximum equivalent transmittance reaching 1.08 at the stratopause level
- (3) an additional increase with the albedo effect, $A=1$, giving an equivalent transmittance more than 1.5 at $z = 0$ km and 1.18 at the stratopause level.

REFERENCES

- ANDERSON D.E. (1983), The troposphere-stratosphere radiation field at twilight : A spherical model, Planet. Space Sci., 31, 1517.
- ANDERSON D.C. and LLOYD S.A. (1990), Polar UV-Visible radiation field : Perturbations due to multiple scattering, ozone depletion, stratospheric clouds, and surface albedo, J. Geophys. Res., 95, 7429.
- ARVESEN J.C., GRIFFIN R.N. Jr. and PEARSON B.D. Jr. (1969), Determination of extraterrestrial spectral irradiance from a research aircraft, Appl. Optics, 8, 2215.
- BASS A.M. and PAUR R.J. (1985), The ultraviolet cross sections of ozone : I. Measurements in Atmospheric Ozone, Proceedings of the Quadriennal Ozone Symposium in Halkidiki, Greece (Edited by Zeferos C. and Ghazi, A.) pp. 606-616, D. Reidel, Hingham Mass. and private communication.
- BROADFOOT A.L. (1972), The solar spectrum 2100-2300 Å, Astrophys. J., 173, 681.
- DOBSON G.M.B. (1966), Annual variation of ozone in Antarctica, Quart. J. Roy. Meteorol. Soc., 92, 549.
- DOBSON G.M.B. (1968), Forty Year's Research on Atmospheric Ozone at Oxford : A History, Applied Optics, 7, 387.
- DÜTCH H.U. (1969), Atmospheric Ozone and Ultraviolet Radiation, Chapter 8 in Vol. 4 of World Survey of Climatology, Elsevier Publ. Cy, Amsterdam, pp. 383-432.
- GÖTZ F.W.P. (1926), Das Strahlungsklima von Arosa, Springer, Berlin, 110 pages.
- HEATH D.F. (1980), A review of observational evidence of short and long term ultraviolet flux variability of the sun. Proc. Int. Conf. on Sun and Climate. CNES Toulouse, 30 Sept. - 3 Oct., pp. 445-450.
- HENDERSON-SELLERS A. and WILSON M.F. (1983), Surface albedo data for climatic modeling, Rev. Geophys. and Space Phys., 21, 1743.

- HENRIKSEN K., STAMNES K. and ØSTENSEN P. (1989), Measurements of solar U.V., Visible and Near I.R. irradiance at 78° N, Atmos. Environment, 23, 1573.
- LABS D., NECKEL H., SIMON P.C. and THUILLIER G. (1987), Ultraviolet solar irradiance measurement from 200 to 358 nm during Spacelab I mission, Solar Phys., 107, 203.
- MACDOWALL J. (1960a), Distribution of atmospheric ozone; A preliminary analysis of some International Geophysical Year observations, Nature, 187, 382.
- MACDOWALL J. (1960b), Some observations at Halley Bay in seismology, glaciology and meteorology, Proc. Roy. Soc. London A256, 149.
- MEIER R.R., ANDERSON D.E. and NICOLET M. (1982), Radiation field in the troposphere and stratosphere from 240-100 nm - I. General analysis, Planet. Space Sci., 30, 923.
- MENTALL J.E., FREDERICK J.E. and HERMAN J.R. (1981), The solar irradiance from 200 to 330 nm, J. Geophys. Res., 86, 9881.
- MENTALL J.E. and WILLIAMS D.E. (1988), Solar ultraviolet irradiances on December 7, 1983 and December 10, 1984. J. Geophys. Res., 93, 735.
- NICOLET M. (1975), Stratospheric ozone : an introduction to its study. Rev. Geophys. Space Phys., 13, 593.
- NICOLET M. (1989), Solar spectral irradiances with their diversity between 120 and 900 nm, Planet. Space Sci. 37, 1249.
- NICOLET M., MEIER R.R. and ANDERSON D.E. (1982), Radiation field in the troposphere and stratosphere - II. Numerical analysis, Planet. Space Sci., 30, 935.
- SCOTTO J., COTTON G., URBACH F., BERGER D. and FEARS T. (1988), Biologically effective ultraviolet radiation : Surface measurements in the United States, 1974 to 1985, Science, 239, 762.
- SIMON P.C. (1978), Irradiation solar flux measurements between 120 and 140 nm. Current position and future needs, Planet. Space Sci., 26, 355.

STAMNES K., HENRIKSEN K. and ØSTENSEN P. (1988), Simultaneous measurement of UV radiation received by the biosphere and total ozone amount, Geophys. Res. Lett., 15, 784.

VANHOOSIER M.E., BARTOE J.-D.F., BRUECKNER G.E. and PRINZ D.K. (1987), Solar irradiance measurements 120-400 nm from Spacelab-2 (results from the SUSIM experiments). IUGG Assembly, Vancouver and private communication.

WEYDE E. and FRANKENBURGER W. (1931), The measurement of ultraviolet radiation, especially of the physiologically active ultraviolet (which produces erythema), by means of the photochemical formation of triphenylmethane dyestuffs from leuco compounds, Trans. Faraday Soc., 27, 561.

WORLD METEOROLOGICAL ORGANIZATION (1985) in Atmospheric Ozone, Chapter 7 p. 349, Geneva, Switzerland.

APPENDIX I

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PUBLISHED BY MASSON, PARIS 1934

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AFTER THE SECOND WORLD WAR

THE BIOLOGIC EFFECTS OF ULTRAVIOLET RADIATION (WITH EMPHASIS ON THE SKIN)

*Proceedings of the First International Conference,
sponsored jointly by
The Skin and Cancer Hospital,
Temple University Health Sciences Center
and
The International Society of Biometeorology*

Edited by

FREDERICK URBACH,
PERGAMON PRESS

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Impact Assessment Program, US Department of Transportation

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3.5. CIAP Monograph Series, DOT-TST-75-55, September 1975

Monograph 5 - Final Report

Impacts of Climatic Change on the Biosphere

Ultraviolet Radiation Effects

Alan Grobecker, Editor in Chief

Prepared for

Department of Transportation

Climatic Impact Assessment Program

Office of the Secretary of Transportation

Washington, D.C. 20590

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