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

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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 [Götz (1926), Springer, Berlin]. 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.

I. 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 1.A and 1.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 Ultraviolettodosimeter 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 World War II, the biological impacts of the UV radiation were re-evaluated 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 World War I. The changes which followed have led to the present situation where the suntan has become almost universal throughout our populations. This is why we can now readily 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 yr of age had had several skin cancers, while the aborigines, although less fully clothed, were immune. This was attributed to the difference in the type of melanin pigmentation. When UVB radiation, filtered by the ozone absorption penetrates the epidermis, it encounters cells, the melanocytes, which create melanin, a pigment that provides a natural defence against sunburn. The nitrogen eumelanins (black and brown macromolecular pigments) that give rise to dark skins provide a better screen than the sulphur phaeomelanins (reddish-brown macromolecular pigments) that give light-coloured skin. The eumelanins protect the dark-skinned populations, while the phaeomelanins, 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, showed that there 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 (Dütsch, 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 (due to World War II!) 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 his UVB dosimeter had a cylindrical form 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 (due to World War II!) and have been lost.

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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.

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, for example, Meier et al., 1982; Nicolet et al., 1982; Anderson, 1983; Henderson-Sellers and Wilson, 1983; Scotto et al., 1988; Stamnes et al., 1988; Henriksen et al., 1989; Anderson and Lloyd, 1990).

3.2. Transmittance and its amplification factor

The transmittance is the primary source function which must be considered for a certain wavelength, for a particular height, and for a specific solar zenith angle .

\[ T(r, z) = S_z(A = 0, MS = 0, \chi, \lambda) \]

\[ = q_0/q_z = \exp \left[ -\tau(z)/(\chi) \right] \] (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 per number of photons cm$^{-2} s^{-1}$ at the top of the Earth’s atmosphere to the number of photons cm$^{-2} s^{-1}$ at the top of the Earth’s atmosphere. The optical depth at wavelength \( \lambda \) for the solar zenith angle \( \chi \) at altitude \( z \) is given by the altitude \( z \) for a particular zenith angle \( \chi \) is defined by the ratio \( M(z, \chi)/M(z, \chi = 0) \).

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, \( z = 0 \) km, where the molecular number density is maximum. Thus, there is a first basic enhanced source function \( S \), between 90 and 0 km.

\[ S(A = 0, MS, \chi, z) = (q_0 + q_{MS})/q_z \] (2)
Solar spectral irradiance in the region of the UVB

Bioklimatisches Ultravioletttdosimeter der I. G. Farbenindustrie.

(a)

(b)

Fig. 1. (a) The bioclimatic ultraviolet dosimeter used in Arosa in 1938–1939. See K. Büttner. Physikalisches Bioklimatologie, Appendix IB. The details on the physical aspects of measurements of the physiologically active ultraviolet radiation by means of the photochemical formation of triphenylmethane dye-stuff from leuco compounds are given in an article published by WEYDE and FRANKENBURGER (1931). (b) Relative effectiveness in the UVB for various wavelengths. Erythema production, bacterial action, ..., cadmium cell, UV Bioclimatic Dosimeter. See Büttner. Appendix IB.

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, \( z_0 = 0 \text{ km} \). Thus, the atmospheric transmittance is increased by a factor \( x \).

\[
S(A = 0, MS, \chi, z) = xTr. \tag{2a}
\]

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

\[
R_n = \frac{S(A = 0, MS \neq 0, \chi, z)}{S(A = 0, MS = 0, \chi, z)} = (q_D + q_{MS})/q_D = 1 + [q_{MS}/q_D]_{z_0 - a \text{ km}}. \tag{3}
\]

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 \( z_0 = 0 \text{ km} \), is

\[
S(A, MS, \chi, z)_{z_0 - a \text{ km}} = \frac{[q_D + q_A + q_{MS} + q_{MSA}]}{q_D}. \tag{4}
\]

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 \( R_n \), (1)
and (4),

$$R_G = \frac{S(A, MS, \chi, z)}{S_0(A = 0, MS = 0, \chi, z)_{z_0 = 0 \text{ km}}}$$

$$= 1 + \left[q_A + q_{MS} + q_{MSA}\right]/q_D$$  \hspace{1cm} (5)

with $z_0 = 0 \text{ km}$. When the ground level is not at $z_0 = 0 \text{ km}$, 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 to 301 nm) an example of numerical values at 5 km (troposphere) and 50 km (stratopause) for an overhead Sun, $\chi = 0$. 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 $1.5 \pm 0.1$ for $A = 0$, and increases to $1.6 \pm 0.1, 1.7 \pm 0.1, 1.9 \pm 0.2, 2.25 \pm 0.20$ and $2.60 \pm 0.30$ 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.

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. Aeronomical parameters in the UVB region

Complete analysis of the amplification of the number of photons available for photochemical processes

<table>
<thead>
<tr>
<th>$\lambda$ (nm)</th>
<th>$A = 0$</th>
<th>$A = 0.10$</th>
<th>$A = 0.25$</th>
<th>$A = 0.50$</th>
<th>$A = 0.75$</th>
<th>$A = 1.0$</th>
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<td>3.59</td>
<td>4.48</td>
<td>5.61</td>
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<td>2.71</td>
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<td>4.25</td>
<td>5.30</td>
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<td>1.84</td>
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<td>2.40</td>
<td>3.05</td>
<td>3.81</td>
<td>4.71</td>
</tr>
<tr>
<td>400</td>
<td>1.64</td>
<td>1.86</td>
<td>2.19</td>
<td>2.81</td>
<td>3.51</td>
<td>4.31</td>
</tr>
</tbody>
</table>
Solar spectral irradiance in the region of the UVB

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 Tschuggen Hotel, large building almost at the centre of this figure (X).
Solar spectral irradiance in the region of the UVB

in the atmosphere which results from molecular scattering and from albedo effects requires simultaneous determination for all solar zenith angles, \( \chi = 0-90 \), for all heights \( z \), for all albedos, \( A = 0-1 \), and for ground levels from the sea level \( z_0 = 0-4 \) km. For that purpose, the determination of the atmospheric optical depth \( \tau_{\text{eff}} \) and an equivalent atmospheric optical depth \( \tau(\text{MS}, A) \) portray the effects.

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

\[
x \tau_{\text{eff}} = e^{-(z, \text{MS}) f(z)}.
\]

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

\[
x \tau_{\text{eff}} = e^{-(z, \text{MS}, A) f(z)}.
\]

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, 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 \( \chi = 0-90 \). 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 \( \tau_{\text{eff}} \) to about 3.5 at \( \chi = 0 \) and to a relatively low equivalent value of the order of 10 at \( \chi = 90 \); 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 \( 10^{-11} \) when the Sun is at the horizon.

The introduction of the additional effect due to the various albedos (Figs 3–6, \( A = 1 \)) 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 \( z = 0 \), corresponds to an optical depth \( \tau_{\text{eff}} \) of about 4.2. This transmittance with the molecular scattering effect yields an equivalent transmittance amplified by about 2.4; it corresponds to an
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 $0.75 \tau_{\text{eff}}, 0.65 \tau_{\text{eff}}, 0.60 \tau_{\text{eff}}, 0.55 \tau_{\text{eff}}$ and $0.5 \tau_{\text{eff}}$, respectively. At $\chi = 90^\circ$, the atmospheric transmittance that corresponds to an optical depth $\tau_{\text{eff}}$ of the order of $85$ is effectively reduced to a corresponding equivalent optical depth of about $0.15 \tau_{\text{eff}}$ for an amplification factor by molecular scattering that is not less than $10^3$.

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

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

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 $\chi = 0$ and $x = 8 \times 10^{-22}$ at $\chi = 90^\circ$, the global basic enhanced source functions attain about $0.65$ and $2 \times 10^{-4}$.

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 $\tau_{\text{eff}}$ that is about $2$ decreases to $1$ by the effect of molecular scattering
Solar spectral irradiance in the region of the UVB

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

<table>
<thead>
<tr>
<th>$\chi$ (degrees)</th>
<th>$T_r$</th>
<th>$x_{\text{MS}}$</th>
<th>$x_{\text{MS},A=1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>6.5 x 10^{-2}</td>
<td>2.4</td>
<td>10.0</td>
</tr>
<tr>
<td>30</td>
<td>4.3 x 10^{-2}</td>
<td>2.6</td>
<td>10.0</td>
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<td>50</td>
<td>1.5 x 10^{-3}</td>
<td>3.0</td>
<td>10.0</td>
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<tr>
<td>65</td>
<td>1.7 x 10^{-4}</td>
<td>4.8</td>
<td>16.0</td>
</tr>
<tr>
<td>75</td>
<td>3.7 x 10^{-5}</td>
<td>25.0</td>
<td>87.0</td>
</tr>
<tr>
<td>80</td>
<td>4.5 x 10^{-6}</td>
<td>6.8 x 10^{-2}</td>
<td>2.5 x 10^{-2}</td>
</tr>
<tr>
<td>83</td>
<td>3.2 x 10^{-9}</td>
<td>5.7 x 10^{-4}</td>
<td>2.1 x 10^{-4}</td>
</tr>
<tr>
<td>87</td>
<td>7.9 x 10^{-15}</td>
<td>3.1 x 10^{-10}</td>
<td>1.1 x 10^{-10}</td>
</tr>
<tr>
<td>90</td>
<td>1.8 x 10^{-22}</td>
<td>2.2 x 10^{-22}</td>
<td>8.3 x 10^{-22}</td>
</tr>
</tbody>
</table>

The $T_r$ is reduced to less than $x_{\text{MS},A=1} = 0.5$ for an albedo $A = 1$. At solar zenith angles greater than $60^\circ$, the albedo effect is reduced, and at $\chi = 90^\circ$ the atmospheric optical depth of the order of $50$ reaches an equivalent value of the order of $8$ that corresponds to less than $0.2 \, \tau_r$. The amplification factor $\chi$ 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 $7 \times 10^{-4}$ at $\chi = 90^\circ$ where the source function is only of order $10^{-15}$; the amplification factor $\chi$ cannot be less than $10^{-17}$.

With increasing wavelength (see Figs 6 and 7, for $\lambda = 315$, 320 and 325 nm) the atmospheric optical depth decreases. At $\chi = 0$, $\tau_r$ 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, 0.2 and 0.1 $\tau_r$. Such equivalent optical depths correspond to an amplification factor of the atmospheric transmittance of the order of $2.35 \pm 0.05$ at $\chi = 0$ and lead to an amplification factor of $10$ for low solar zenith angles. Thus, such photolytic processes as the photodissociation 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 $z_r = 0$ km for an overhead Sun $\chi = 0$, varies approximately by a factor of 4, that is 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 $\chi = 90^\circ$ increases from about 30 to 90, the corresponding amplification varies from about $10^{12}$ to $10^{12}$, 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 $\tau$.  

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 5),

<table>
<thead>
<tr>
<th>Wavelength interval (nm)</th>
<th>$q_{\text{SUSIM}}$ (1 nm)</th>
<th>Ratio S/SIM ARVESEN</th>
<th>Ratio S/SIM HEATH</th>
<th>Ratio S/SIM MENTALL I</th>
<th>Ratio S/SIM MENTALL II</th>
</tr>
</thead>
<tbody>
<tr>
<td>300–301</td>
<td>0.603</td>
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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 (Figs 9, 10, 11 and 12). A comparison between the results of Mentall and Heath between 300 and 330 nm is shown in Fig. 9 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 irradiance of Spacelab 1 (Labs et al., 1987) corresponding to three 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\% lower than the SUSIM data. On the other hand, the values adopted in the WORLD METEOROLOGICAL ORGANIZATION (1985) 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. Figure 13a and b based on experimental data of Bass and Paur (1985) illustrates the variation of the O\(_3\) absorption cross-section for temperatures between

![Fig. 9. Comparison of solar spectral irradiances between 300 and 330 nm obtained by Mentall et al. (1981) and by Heath (1980).](image-url)
Fig. 10. Solar spectral irradiances between 300 and 325 nm observed by Van Hooser et al. (1987).

Fig. 11. Solar spectral irradiances between 300 and 325 nm from SUSIM (Van Hooser et al., 1987) Spacelab 2 for 1 nm intervals compared with the irradiances of Spacelab 1 (Labs et al., 1987).
Solar spectral irradiance in the region of the UVB

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

Fig. 13. (a) Ratios of \(O_3\) absorption cross-sections between 290 and 315 nm based on the experimental results of Bass and Paur (1985).

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

200 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 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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**REFERENCES**

Anderson D. E.

Anderson D. C. and Lloyd S. A.

Arvesen J. C., Griffin R. N. Jr and Pearson B. D. Jr

Bass A. M. and Paar R. J.

Broadfoot A. L.

Dobson G. M. B.

Dobson G. M. B.

Dütsch H. U.

Götz F. W. P.


Solar spectral irradiance in the region of the UVB

1980 | A review of observational evidence of short and long


1987 | Ultraviolet solar irradiance measurement from 200 to 358 nm during Spacelab I mission. Solar phys. 107, 203.


1987 | Solar irradiance measurements 120-400 nm from Spacelab-2 (results from the SUSIM experiments). IUGG Assembly, Vancouver and private communication.

1931 | The measurement of ultraviolet radiation, especially of the physiologically active ultraviolet (which produces erythema), by means of the photochemical formation of triphenylmethane dyeustuffs from leuco compounds. Trans. Faraday Soc. 27, 561.

APPENDIX I

A. ANATOMY OF THE BIBLIOGRAPHY BEFORE THE SECOND WORLD WAR
PUBLISHED BY MASSON, PARIS 1934

TRAITÉ
DE CLIMATOLOGIE
BIOLOGIQUE
ET MÉDICALE

PRÉFACE (Pr. d’Arsenval)
INTRODUCTION GÉNÉRALE (M. Péry)
INTRODUCTION HISTORIQUE (M. Van der Elst)

LIVRE PREMIER
Climatophysique et Climatochimie

INTRODUCTION (M. Sorre)

I. - Éléments météorologiques des climats.
   Les éléments météorologiques du climat (A. Baldit) .......................................................... 10
   Electricité atmosphérique (Ch. Maurain) .................................................................................. 66
   Radioactivité de l’atmosphère (E. Salles) ............................................................................... 82
   Air atmosphérique (G. Urbain) ............................................................................................... 90
   Corpses inertes et vivants de l’atmosphère (A. Rochaix) ......................................................... 98

II. - Facteurs cosmiques des climats.
   Les facteurs cosmiques du climat (A. Baldit) ....................................................................... 106
   La radiation du soleil et du ciel (W. Moriköfer) ..................................................................... 127

III. - Éléments telluriques des climats.
   Les facteurs géographiques du climat (A. Baldit) ................................................................. 205
   Les facteurs géologiques et telluriques des climats (P. Urbain) ............................................ 228
   L’eau de mer (E. Barral et P. Barral) .................................................................................... 244
   Eaux douces (E. Barral et P. Barral) ..................................................................................... 256

IV. - Constitution et classification des climats.
   Classification biologiques et médicales des climats (M. Sorre) .......................................... 261

LIVRE II
Climatographie générale

INTRODUCTION .......................................................................................................................... 267
   Conditions générales des climats régionaux et locaux (E. de Martonne) .............................. 267

I. - Climats d’Europe.
   Les climats de la France (A. Allix) ...................................................................................... 293
   Les climats de l’Europe (E. Bénévent) .................................................................................. 386
   Climat de la Suisse (W. Moriköfer) ..................................................................................... 421

II. - Climats du globe.
   Les climats de la terre moins l’Europe (M. Sorre) ............................................................... 438
   Les climats polaires (M. Zimmermann) ............................................................................... 479

LIVRE III
Bioclimatologie

INTRODUCTION (H. Cardot) ...................................................................................................... 487

I. - Bioclimatologie générale (G. Bohn) .................................................................................. 490

II. - Phytoclimatologie (P.-A. Burollet) .................................................................................. 501

III. - Zooclimatologie (climats et espèces animales) (J. Guiart) ............................................. 519
   Zootéchnie climatologique (E. Letard) .................................................................................. 532
Solar spectral irradiance in the region of the UVB

**LIVRE IV**

**Climatologie humaine**

**INTRODUCTION (R. VAN DER ELST)** ................................................................. 539

I. — **Climatopsychologie (R. VAN DER ELST)** .................................................. 546

II. — **Ethnoclimatologie (faces et climats) (J. GUIART)** ...................................... 556

III. — **Socioclimatologie.**

Le climat et les sociétés humaines (M. SORRE) ................................................... 565
Action de l’activité périodique solaire sur les phénomènes sociaux (A.-L. DE TCHIORSKY) .................................................. 576

IV. — **Esthétoclimatologie (LARGER-LAVASTINE)** ............................................ 587

**LIVRE V**

**Physioclimatologie normale et pathologique**

**INTRODUCTION (P. CARNOT)** ........................................................................... 601

I. — **Physioclimatologie générale des climats.**

Effets des agents météorologiques et chimiques (J. CLUZET et T. KOEFMAN) ................................................................. 606
Effets physiologiques des rayons solaires (A. LUMIERE) ........................................ 645
Action de l’ionisation de l’atmosphère et de l’ionisation artificielle de l’air sur les organismes sains et les organismes malades (A.-L. DE TCHIORSKY) .................................................. 661
Action de la radioactivité de l’atmosphère sur l’organisme (A. CHEVALLIER) ........ 674
Analyse de l’action des climats sur les diverses fonctions de l’organisme sain et pathologique (A. DESGREZ, H. CAROT et D. SANTENOLE) .................................................. 679

II. — **Physioclimatologie spéciale des climats. Les grands climats thérapeutiques.**

1° **ACTION DES PRINCIPAUX TYPES BIOLOGIQUES DE CLIMATS**

Climats tempérés (P. BLUM) .................................................................................. 752
Climat continental (P. BLUM) .............................................................................. 767
Climatologie des hauts plateaux (C. MONGE) ...................................................... 776
Le climat urbain (M. SORRE) ............................................................................. 786
Climat de montagne (M. RICY et M. MILHAUD) ................................................... 792
Climat marin (G. BAILLOU) .................................................................................. 905
La radiation du soleil et du ciel à la mer (M. D’HALUN) ...................................... 934
Le climat de col et de plateau moyen (F. DUMAREST, A. CHRETIEN et H. MOLLARD) .............................................................................. 945
Climats de plaine et climats de vallée (HERVE et REYCASSE) ......................... 950
Le climat de lac (W. MORIKOFER et P.-M. BESSE) ........................................... 958
Climat de forêt (P. BLUM) .................................................................................... 966
Le climat désertique (R. BURNAND et M. GILBERT) .......................................... 971

2° **ACTION DES PRINCIPAUX ÉLÉMENTS CLIMATOThÉRAPEUTIQUES.**

Les effets physiologiques et thérapeutiques des bains de soleil (A. ROLLIER) ........ 981
Action physiologique et thérapeutique des bains de mer (G. BARRAUD) .......... 1001
L’eau de mer en usage interne (J. CARLES) ...................................................... 1007

**LIVRE VI**

**Climatopathologie**

**INTRODUCTION (A. ROCHAIX)** ........................................................................... 1013

I. — **Climatopathologie générale.**

Météoropathologie (G. MOURIQUAND) ................................................................. 1017
Telluropathologie (A. LUMIERE) ......................................................................... 1030
L’action de l’activité périodique solaire sur les epidémies (A.-L. DE TCHIORSKY) .............................................................................. 1034
L’action de l’activité périodique solaire sur la mortalité générale (A.-L. DE TCHIORSKY) .............................................................................. 1042
Climatogeographie des maladies (JULES GUIART) ............................................. 1046
Climatopathologie vétérinaire (M.-L. AUGER) ................................................. 1072
Action pathogène et pathologique des facteurs climatiques (A. ROCHAIX) .... 1081
Adaptation aux climats (A. ROCHAIX) ................................................................. 1097
Hygiène climatique (A. ROCHAIX) .................................................................... 1104

II. — **Climatopathologie spéciale.**

Climatopathologie tropicale (CH. GARIN) ............................................................ 1109
Climatopathologie désertique (L. TASON et R. NEVEU) .................................... 1133
Climatopathologie des régions polaires (O. ABS) .............................................. 1153
Climatopathologie urbaine (G. MOURIQUAND) ................................................. 1167
Climatopathologie des hauts plateaux (CARLOS MONGE) .............................. 1175
INTRODUCTION (G. GIRAUD) .................................................................................................................. 1209

I. — Pratiques climatothérapeutiques générales.
   Techniques de cure communes aux stations climatiques (F. DUMAREST et H. MOLLARD) .............. 1216
   Éducation physique, sports et climats (LATARRE) ............................................................................ 1225
   Cures hydrominérales et cures climatiques associées (H. PAILLARD) ......................................... 1244
   Les villégies (J. CARLES) .................................................................................................................. 1251
   Changements de climat et voyages (M. R. BURNAND et P.-R. JOLY) ............................................. 1258

II. — Pratiques climatothérapeutiques spéciales.
   Pratique de la cure héliothérapique (C.-M. BUFNOR et F. CAPPELLE) ........................................... 1265
   Pratique thalassothérapeutique (GEORGES BARRAUD) ................................................................. 1284
   Les bains de boues marines (ET. BARRAL et M. BARRAL) ............................................................. 1294
   Technique des bains de rivière et de lait (J. CLUZET et T. KOFMAN) ............................................ 1301
   Pratique de la cure sanatoriale et hospitalière maritime (E. SORRELL et A. DELAHAYE) .............. 1304
   Voyages en mer (M.-A. LOR) ............................................................................................................. 1311
   La pratique de la cure sanatoriale chez les tuberculeux pulmonaires (F. DUMAREST et H. MOLLARD) .................................................................................................................. 1317
   Pratique de la cure sanatoriale climatique pour nerveux (R. DUBOIS) ......................................... 1327

III. — Organisation et fonctionnement de la station climatique.
   Organisation de la station climatique (M.-G. BAUDOIN et M. DOYON) ........................................ 1335
   Réseau de climatologie générale. Station climatologique médicale (A. BALDIT) ....................... 1345
   L'organisation des services de climatologie et de climatophysiologie dans le divers pays (W. MÖRKOFER) ......................................................... 1357
   Hygiène des stations climatiques (A. ROCHAIX) ............................................................................. 1366

IV. — Climatisme social.
   Préventoriums (G. POIX) .................................................................................................................. 1381
   Villages-sanatoria (R. PIERRET) ....................................................................................................... 1388
   Camps climatiques (MOLINÉRY) ..................................................................................................... 1400
   Écoles de plein air (G. VITRY) .......................................................................................................... 1409
   Législation des stations climatiques (V. GARDETTE) ....................................................................... 1414

LIVRE VIII

Climatographie médicale.

Climats médicaux et thérapeutiques, stations climatiques.

INTRODUCTION (J. SELLIER) ................................................................................................................. 1423

STATIONS CLIMATIQUES FRANÇAISES

I. — Stations climatiques d'altitude.
   Climats et stations climatiques des Alpes françaises (M. PIÉRY et J. LANGÉNIEUX) .................... 1429
   Climats et stations climatiques des Pyrénées françaises (M. SERR) ............................................. 1473
   Climats et stations climatiques des Corbières et de la Montagne noire (M. SERR) ..................... 1500
   Climats et stations de cure du Massif central (GIRAUD) ............................................................... 1509
   Climats et stations de cure des Vosges occidentales (M. PERRIN et Élisabeth PERRIN) ............ 1569
   Climats et stations de cure des Vosges orientales (P. BLUM) ..................................................... 1590
   Climats et stations climatiques du Jura (D. SANTENOISE, L. MERKLEN et GRANDPIERRE) ........ 1602
   Climats et stations climatiques de l'Arrière-Côte d'Azur (J. Bertier) ............................................ 1624

II. — Stations climatiques maritimes et insulaires.
   Climats et stations climatiques de la met du Nord et de la Manche (M. DUHOT) ....................... 1651
   Climats et stations climatiques de l'Atlantique (J. SELLIER) ....................................................... 1682
   Climats et stations climatiques du littoral méditerranéen (G. GIRAUD) .................................... 1700
   Climats et stations climatiques de la Corse (G. DUHOT) ............................................................. 1763

III. — Stations climatiques de plaine et de vallée.
   Climats et stations de cure des plaines du Sud-Ouest (G. GIRAUD) ........................................... 1770
   Climats et stations de cure de la Basse Provence (G. GIRAUD) .................................................. 1801
Climats et stations de cure des plaines de la Seine et de la Loire (G. Giraud) ................................................................. 1819
Climats et organisations climatiques de la région parisienne (M. Villaret et Justin-Besançon) ........................................... 1862
Climats et stations climatiques de la plaine d'Alsace (P. Blum) ......................................................................................... 1873
Climats et stations de la Flandre, de la Picardie et des Ardennes (E. Duhot) ................................................................. 1881
Climats et stations de cure de la Normandie et du Massif armoricain (P.-R. Joly) ......................................................... 1886

IV. — Stations climatiques de lacs.
Stations françaises de lac (P. Blum) ................................................................................................................................. 1897

V. — Stations climatiques de forêts.
Stations françaises de forêt (P. Blum) ............................................................................................................................... 1902

STATIONS CLIMATIQUES EUROPÉENNES

I. — Stations climatiques de l'Europe océanique.
Les climats du Portugal (A. Narciso) .......................................................................................................................... 1906
Climats et stations climatiques de la Grande-Bretagne (A. Cawadias) ................................................................. 1972
Climats et stations climatiques de la Belgique (N. Terwagne) ......................................................................................... 1932
Climats et stations climatiques du Grande-Duché de Luxembourg (E. Klein et Schumacher) .................................. 1942
Climatotherapie des Pays-Bas (J. Van Breemen) ........................................................................................................... 1947
Climats et stations climatiques du Danemark (A. Faber) ................................................................................................. 1955
Climats et stations climatiques de la Norvège (G. Gade) ................................................................................................. 1960
Climats et stations climatiques de la Suède (Gunnar Fiksdöm) .................................................................................... 1968

II. — Stations climatiques de l'Europe Méditerranéenne.
Climats et stations climatiques de l'Espagne (H.-R. Pinella) ......................................................................................... 1979
Climats et stations climatiques d'Italie (G. Cerisole) ........................................................................................................ 1990
Climats et stations de cure de Grèce (G.-T. Flora) ........................................................................................................... 2002

III. — Stations climatiques de l'Europe orientale.

IV. — Stations climatiques de l'Europe centrale.
Climats et stations climatiques de l'Allemagne. Climat marin (H. Heberlin) ................................................................. 2020
Stations de cures climatiques de l'Allemagne continentale (C. Heberlin et O. Ihlenhus) .................................................. 2031
Climats et stations climatiques de la Pologne (L. de Korczynski) ..................................................................................... 2039
Climats et stations climatiques de Tchécoslovaquie (V. Kucera et J. Kopecki) ......................................................... 2052
Climats et stations climatiques de l'Autriche (V. Conradi) ............................................................................................. 2058
Climats et stations climatiques de Hongrie (Z. Dalmady) ............................................................................................... 2067
Climats et stations climatiques de la Suisse (P.-M. Besse et J. Weber) ................................................................. 2076
Climats et stations climatiques de la Roumanie, Bulgarie et Yougoslavie (Scherbakov) .................................................. 2085

LES CLIMATS DU GLOBE

I. — Stations climatiques de l'Afrique.
Climats et stations climatiques de l'Afrique du Nord (G. Aubry) .................................................................................. 2103
Climats et stations climatiques de l'Égypte (R. Burnand) ............................................................................................... 2133

II. — Stations climatiques de l'Amérique.
Climats et stations climatiques des États-Unis et du Canada (G. Hinsdale) ................................................................. 2139
Climats et stations climatiques de l'Amérique du Sud (G. Sayago) .................................................................................. 2150

III. — Stations climatiques de l'Asie.
Climats et stations climatiques des Indes (A. Cawadias) ................................................................................................. 2167
Climats et stations climatiques du Japon (K. Manabe) ................................................................................................. 2174

IV. — Climatologie médicale des colonies françaises.
Considérations générales (L. Tanon) .......................................................................................................................... 2181
Climatologie de l'Afrique occidentale française (A. Guilleu) ......................................................................................... 2184
Climatologie de l'Afrique équatoriale française (M. Blanchard) .................................................................................... 2194
Climatologie du Cameroun (G. Martin) ......................................................................................................................... 2209
Climatologie du territoire du Togo sous mandat français (M. Lefèvre) ............................................................................ 2227
Climatologie de Madagascar (M. Fontenoy) ................................................................................................................... 2238
Climatologie de la Côte française des Somalis (M. Passa) ............................................................................................... 2249
Climatologie de la Syrie et du Liban (J. Trabaud) ........................................................................................................... 2256
Climatologie de l'Indo-Chine (S. Abbattucci) ................................................................................................................ 2275
Climatologie des Établissements français de l'Inde (V. Labernadie) ............................................................................... 2292
Climatologie des Antilles françaises (M. Léger) ............................................................................................................... 2307
Climatologie des îles Saint-Pierre et Miquelon (M. Cazanove) ....................................................................................... 2319
Climatologie de la Guyane française (M. Cazanove) ........................................................................................................ 2321
Climatologie des Établissements français de l'Océanie (L. Sasportas) .......................................................................... 2324
M. NICOLET

LIVRE IX
Clinique Climatothérapeutique.

INTRODUCTION (E. DUHOT) ........................................................................................................................................... 2329

I. — Cures climatiques en général.
   Mode d'action générale des cures climatiques (G. SARDOU) .................................................................................. 2340
   Le contrôle des cures climatiques (M. PIÉRY) ........................................................................................................ 2347
   Indications et contre-indications générales des cures climatiques (P.-M. BESSE et WEBER) .................................. 2365

II. — Cures climatiquês et maladies générales.
   Cures climatiques et maladies de la nutrition (M. LOEPER et JUSTIN-BESANÇON) .................................................. 2376
   Cures climatiques et lithiases (M.-P. WEIL) ............................................................................................................. 2387
   Cures climatiques et syphilis (J. NICOLAS et J. GATÉ) ............................................................................................ 2395
   Cures climatiques et maladies des pays chauds (M. PIÉRY et M. MILHAUD) .......................................................... 2402
   Cures climatiques et maladies de l'enfance (M. PIÉRY) ............................................................................................ 2413

III. — Cures climatiques et maladies des appareils.
   Cures climatiques de la tuberculose pulmonaire (M. PIÉRY) .................................................................................. 2424
   Cures climatiques en oto-rhino-laryngologie (F. COLLET) ..................................................................................... 2479
   Cures climatiques et affections de l'appareil respiratoire (V. CORDIER) ................................................................. 2489
   Cures climatiques et maladies de l'appareil cardio-vasculaire (M. DUMAS) ............................................................. 2498
   Cures climatiques des maladies du rein (F. RATHERY) ............................................................................................. 2506
   Cures climatiques dans les maladies du tube digestif (M. MILHAUD) ................................................................. 2513
   Cures climatiques des maladies du foie (P. SAVY et P. DELORE) .......................................................................... 2527
   Cures climatiques des maladies du sang et des organes hématopoïétiques (J. RIEUX et LE BOURDELLES) .............. 2533
   Cures climatiques des maladies du système nerveux (LAINGEL-LAVASTINE) .......................................................... 2542
   Cures climatiques des maladies de la peau (J. NICOLAS et J. GATÉ) ................................................................. 2557
   Cures climatiques et affections chirurgicales (M. VIGNARD) ............................................................................... 2574
   Cures climatiques et tuberculose génito-urinaire de l'homme (L. THÉVENOT) ..................................................... 2590
   Cures climatiques en gynécologie (A. AIMES) ............................................................................................................ 2598
   Cures climatiques et maladies des yeux (ET. et J. ROLLET) .................................................................................. 2605

INDEX ALPHABITIQUE ........................................................................................................................................... 2613

B. Physikalische Bioblimatometrie Probleme und Methoden, (156 pages)

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Akademische Verlagsgesellschaft M.3.H. Leipzig, 1938

Einleitung ........................................................................................................................................................................... 1

Teil I: Strahlung .............................................................................................................................................................. 6
   (a) Einteilung der Strahlenarten .................................................................................................................................. 6
   (b) Schwächung und Umwandlung der Sonnenstrahlung ............................................................................................ 7
   (c) Die Meßgeräte der Sonnen- und Himmelsstrahlung (Wärme und Licht) .............................................................. 19
   (d) Die Ultraviolett-Meßgeräte ....................................................................................................................................... 22
   (e) Die Temperaturstrahlung ......................................................................................................................................... 26
   (f) Die Strahlendurchlässigkeit der Haut ..................................................................................................................... 33
   (g) Spezifische Strahlenwirkungen des Ultraviolett B ................................................................................................. 40
   (h) Biologische Wirkungen der übrigen Spektralbereiche ......................................................................................... 52
   (i) Das Ultraviolettlicht ................................................................................................................................................. 54
   (k) UV-Normalwerte und Strahlendosierung ............................................................................................................. 62
   (l) Das Wärmestrahlungsklima ...................................................................................................................................... 65

Teil II: Wärmeaushalt ....................................................................................................................................................... 68
   (a) Die Bestandteile des Wärmeaushaltes .................................................................................................................... 68
   (b) Die Energiebildung durch Verbrennungsvorgänge im Körper ............................................................................... 69
   (c) Die Wärmespeicherung ........................................................................................................................................... 70
   (d) Die Größe der Oberfläche ....................................................................................................................................... 72
   (e) Der Wärmetransport im Körper ................................................................................................................................. 73
   (f) Der äußere Wärmestrom durch Leitung-Konvektion ............................................................................................ 79
   (g) Der äußere Wärmestrom durch Strahlung und der 'trockene' Wärmeverlust ............................................................. 88
   (h) Die Hauttemperatur .................................................................................................................................................. 90
   (i) Die Summenwirkung von Wind, Strahlung und Temperatur .................................................................................. 95
   (k) Wärme- und Wasserverlust der Haut durch Verdunstung .................................................................................... 109
   (l) Der Wärmeverlust durch Atmung ............................................................................................................................. 116
APPENDIX II

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

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CONTENTS

INTRODUCTION (F. URBACH) ................................................................. 1

Historical Note ................................................................................. 1

Sunburn and Suntanning (K. W. HAUSSE and W. VAHLE) (Translated by F. URBACH) ............. 3

Chemical and Biochemical Effects of Ultraviolet Radiation .................. 23

Chairmen: H. F. BLUM and A. KELNER

Introductory Remarks (H. F. BLUM) ................................................ 25

Immediate Effects of Light (A. L. NORINS) ..................................... 31

Ultraviolet Light Effects on Proteins (E. YEAKERS) .......................... 37

Biochemical Effects of Ultraviolet Light on DNA (K. C. SMITH) ........ 47

The Mechanism of Action of the Skin-photosensitizing Furocoumarins (L. MUSAJO and G. RODRIGUEZ) .......... 57

Effects of Ultraviolet Radiations on Some Activities of Animal Cells (A. C. GIESE) ................. 61

Biological Aspects of Ultraviolet Damage. Photoreactivation, and Other Repair Systems in Microorganisms (A. KELNER) ........... 77

Hyperplasia Induced by Ultraviolet Light: Possible Relationship to Cancer Induction (H. F. BLUM) ........... 83

Artificial Production of Ultraviolet Radiation ................................. 91

Chairmen: P. B. ROTTIER and F. URBACH

Artificial Production of Ultraviolet Radiation, Introduction and Historical Review (V. SCHÄFER) ........... 93

Solar Simulation for Phototesting of Human Skin (F. URBACH) ........ 107

Ultraviolet Lasers (S. FINE and E. KLEIN) ..................................... 115

Design and Construction of High-intensity Monochromators (D. BERGER, I. MAGNUS, P. B. ROTTIER,
R. M. SAYRE and R. G. FREEMAN) .................................................. 125

Optics of the Skin ................................. 139

Chairmen: F. DANIELS and K. G. HANSEN

Optical Properties of Turbid Materials (J. T. ATKINS) ........................ 141

Optics of the Skin as Related to Ultraviolet Radiation (F. DANIELS Jr) .............. 151

Transmission Through Skin of Ultraviolet and Visible Radiation 280-500 nm (K. G. HANSEN) ...... 159

Comments on the Stratum Corneum (A. M. KLEGMAN) .................... 165

Discussion on Skin Optics ............................................................... 169
Biologic Action Spectra ................................................................. 173
Chairmen: I. A. MAGNUS and W. CURWEN

Biologic Action Spectra, Introduction and General Review (I. A. MAGNUS) ................................................................. 175

Physiologic Response of Human Skin to Ultraviolet Light (M. A. EVERETT, R. M. SAYRE and R. L. OLSON) .................................................. 181

The Ratio of the 260/300 nm MED's in the Judgement of Skin Sensitivity to Short Wave Ultraviolet Radiation (P. B. ROTTER) .................................................. 187

Abnormal Action Spectra (A. WISKEMANN) .................................................. 197

Effects of Ultraviolet and Visible Radiation and the Production of Free Radicals in Skin (M. A. PATHAK and K. STRATTON) .................................................. 207

Action Spectra for Acute Effects of Monochromatic Ultraviolet in Mouse Skin (B. E. JOHNSON) .................................................. 223

Production and Measurement of Ultraviolet Erythema .................................................. 235
Chairmen: J. C. VAN DER LEUN and B. E. JOHNSON

The Effects of Natural Sunlight on Human Skin (K. J. K. BUETTNER) .................................................. 237

Photorecovery of Ultraviolet Erythema (J. C. VAN DER LEUN and TH. STOOF) .................................................. 251

Evaluation and Measurement of Ultraviolet Erythema (H. TRONNIER) .................................................. 255

Measurement of Erythemat and Pigmentary Responses to Ultraviolet Radiation of Different Spectral Qualities (R. BREIT and A. M. KLAGMAN) ................. 267

Model Systems for Ultraviolet Erythema .................................................. 277

Vascular and Neoplastic Changes in Mice Following Ultraviolet Radiation (P. F. FORBES and F. URBACH) .................................................. 279

Use of Guinea-pigs in Photobiologic Studies (L. C. HARBER) .................................................. 291

Discussion .................................................. 295

Pigmentation .................................................. 297

Chairmen: M. S. BLOIS and K. HEMPEL

Recent Developments in the Physics and Chemistry of the Melanins (M. S. BLOIS) .................................................. 299

Biostynthesis of Melanin (K. HEMPEL) .................................................. 305

Genetics of Mammalian Pigmentation (W. C. QUEVEDO JR) .................................................. 315

Panel Discussion on the Functions of Melanin (M. S. BLOIS, T. B. FITZPATRICK, F. DANIELS JR and W. C. QUEVEDO) .................................................. 325

Physics of the Atmosphere .................................................. 327

Chairmen: L. KOLLER and J. LENOBLE

The Physics of the Atmosphere (L. KOLLER) .................................................. 329

The Depletion of Ultraviolet Radiation by Atmospheric Ozone (J. LONDON) .................................................. 335

Diffusion du Rayonnement Ultraviolet dans l'Atmosphère (J. LENOBLE) .................................................. 341

Spectral Intensity of Natural Ultraviolet Radiation and its Dependence on Various Parameters (P. BENER) .................................................. 351

Consideration of Sky Ultraviolet Radiation in the Measurement of Solar Ultraviolet Radiation (R. SCHULZE and K. GRAFE) .................................................. 359

Measurement of Natural Ultraviolet Radiation .................................................. 375
Chairmen: P. BENER and D. F. ROBERTSON

Measurement of Natural Ultraviolet Radiation: Historical and General Introduction (R. STAIR) .................................................. 377

Instrumentation for the Measurement of Solar Ultraviolet Radiation (A. J. DRUMMOND and H. A. WADE) .................................................. 391

Critical Discussion of Methods for Measurement of Natural Ultraviolet Radiation (P. BENER) .................................................. 409

Pilot Study of Ultraviolet Radiation in Los Angeles (J. S. NADER) .................................................. 417

Long-term Field Measurements of Erythemally Effective Natural Ultraviolet Radiation (D. F. ROBERTSON) .................................................. 433

Chemical Dosimetry of Ultraviolet Light (R. E. DAVIS) .................................................. 437

Physiological Effects of Solar Ultraviolet Radiation .................................................. 445

Chairmen: E. SEIDL and W. CLARK

The Influence of Ultraviolet Radiation on the Healthy Adult (E. SEIDL) .................................................. 447

Seasonal Variations in Ultraviolet Sensitivity of Normal Skin (H. BRODTHAGEN) .................................................. 459

Ultraviolet Absorption in the Cornea of Arctic and Alpine Animals (P. F. SCHOLANDER, L. IRVING, E. A. HEMMINGSEN and E. BRADSTREET) .................................................. 469

Alterations in Epidermal Lysosomes Following Ultraviolet Light Exposure (R. L. OLSON and M. A. EVERETT) .................................................. 473

Pathologic Effects of Ultraviolet Radiation (General) .................................................. 477

Chairmen: L. HARBER and H. BRODTHAGEN

Polymorphous Light Eruption (H. BRODTHAGEN) .................................................. 479

Symposium on Phototoxicity and Photodermatitis .................................................. 487

Basic Aspects of Cutaneous Photosensitization (M. A. PATHAK) .................................................. 489

Mechanisms of Photopathological Reactions (H. IPPEN) .................................................. 513

Classification and Characteristics of Photoallergy (L. C. HARBER and R. L. BAER) .................................................. 519
Solar spectral irradiance in the region of the UVB 529

Photoallergy and Phototoxicity Due to Drugs (W. BURCKHARDT) ............................................................. 527
Testing for Phototoxicity and Photoallergy (O. F. JILLSON) ........................................................................... 533
Pathologic Effects of Ultraviolet Radiation (Cancer) ....................................................................................... 541
Chairmen: A. KOPF and D. GORDON
Quantitative Aspects of Cancer Induction by Ultraviolet Light: Including a Revised Model (H. F. BLUM) 543
Ultraviolet Light Carcinogenesis (J. H. EPSTEIN, K. FUKUYAMA and R. L. DOBSON) .......................... 551
Effects of Long-wave Ultraviolet Radiation on Polycyclic Hydrocarbon Carcinogenesis (L. SANTAMARIA and G. GIORDANO) ................................................................. 569
Correlation of Observed Ultraviolet Exposure and Skin-cancer Incidence in the Population of Queensland and New Guinea (D. F. ROBERTSON) .................................... 619
Deaths from Skin Cancer in Queensland, Australia (D. GORDON and H. SILVERSTONE) ....................... 625
Geographic Pathology of Skin Cancer (P. URBACH) ......................................................................................... 635
Discussion Following the Panel on Pathologic Effect of Ultraviolet Radiation (Cancer) (A. W. KOPF) .... 651
Phototherapy and Protection from Ultraviolet Radiation ................................................................................. 655
Chairmen: A. WISCKEIMANN and G. FINDLAY
Ultraviolet Therapy at the North Sea Coast (J. HARTUNG) ........................................................................ 657
‘Blitzergerat’ Therapy (E. SHIDH) ..................................................................................................................... 663
Ultraviolet Irradiation in Dermatology (Excluding Heliotherapy) (G. FORCK) ........................................ 673
Topical Agents for Protection Against Ultraviolet Radiation (H. IPPEN) .................................................... 681
Systemic Agents for Protection Against Ultraviolet Radiation (A. WISCKEIMANN) ................................ 689
Oral Intercipitives That Do Not Work (G. H. FINDLAY) .............................................................................. 693
INDEX 697

APPENDIX III

AFTER THE DEBATE OF THE SUPersonic TRANSPORT PROJECT (1975)

Impact Assessment Program, U.S. Department of Transportation

3.1. First Conference, February 1972
The Biological Effects of Ultraviolet Radiation on Man, Animals and Plants (KENDRIC C. SMITH) 243

3.2. Second Conference, November 1972
SESSION VII: BIOLOGICAL IMPACT
Chairman: ALAN J. GROBECKER
Department of Transportation
Status of the CIAP Biological Impact Project (DONALD R. SHELTON) .................................................. 369
Ultraviolet Radiation of Sunlight and Skin Cancer (HAROLD F. BLUM) ............................................. 373
Ultraviolet Radiation and Photosynthesis (EDWARD B. KNIPPING) .................................................. 379
Ecologic Considerations of Solar Radiation Change (MARTYN M. CALD Wesley) .......................... 388
Agronomic Effects of Climatic Change (R. H. BIGGS and J. F. BARTHOLOC) ............................... 394
Remarks on Determining Social and Cost Measures of Climatic Changes (HENRY M. PESKIN) .... 404

3.3. Third Conference, February–March 1974
BIOLOGICAL EFFECTS OF CLIMATIC CHANGES
Chairman: MARTYN M. CALDWEU
Utah State University
Plant Response to Elevated UV Intensities (M. M. CALDWEU, W. F. CAMPEUE, and W. R. SISIGN) 482
Effects of UV Radiation on Agricultural Productivity (J. F. BARTHOLOC, L. H. HALSLEY and R. H. BIGGS) 498
A Preliminary Assessment of the Effects of UV Irradiation on Aquatic Microorganisms and Their Ecosystems (JOHN CALKINS) ................................................................. 505
An Epidemiological Index for Skin-Cancer Incidence (A. E. S. GREEN and T. MO) ............................ 518
Field Measurements of Biologically Effective Ultraviolet Radiation and Its Relation to Skin Cancer in Man (FREDERICK URBACH, DANIEL BERGER and RONALD E. DAVIES) 523
Cell-Population Growth in Cancers Induced by Ultraviolet Radiation (HAROLD F. BLUM) ........ 536
Effect of Climate on Non-Domestic Wheat Production (CLARENCE SAKAMOTO) ............................ 539

3.4. Fourth Conference, February 1975

BIOLGICAL AND ECONOMIC IMPACT

Effects on Plants of Increased UV-B Radiation (R. H. Biggs) .......................................................... 62
Estimate of the Effect of Ozone Reduction in the Stratosphere on the Incidence of Skin Cancer in Man (Frederick Urbach and Ronald E. Davies) .................................................. 66
Potential Effects on Aquatic Ecosystems of Increased UV-B Radiation (D. Stuart Nachtey) .............. 79
A Summary of Estimated Impacts of Climatic Change on Crop Productivity (Ray E. Jensen) ............... 87
Economic Analyses of Pollution Resulting from Stratospheric Flight: a Preliminary Review (Ralph C. d’Arge) .................................................................................................................. 97
Discussion ........................................................................................................................................... 108

THEORY OF RADIATIVE TRANSFER

The UV Radiation Field in the Stratosphere (N. Sundaraman) ............................................................. 234
Results from Recent Solar Radiation Calculations (Frederick M. Luther) ........................................... 242
Determining Atmospheric Composition from Vertical Profiles of Daytime Limb Brightness (K. Ya. Kondratyev, O. M. Pokrovsky and M. A. Sporodenok) .................................................. 254
Discussion ........................................................................................................................................... 263

VISIBLE-ULTRAVIOLET RADIOMETRY

WB57F-Borne Measurements of UV Flux and Ozone Overburden (Bach Sellers and Frederick A. Hansen) ..... 398
Erythemal Ultraviolet Solar Radiation and Environmental Factors (L. Macht, G. Cotton, W. Hass and W. Komhyr) .................................................................................................................. 405
Discussion ........................................................................................................................................... 411

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

CONTENTS

CHAPTER I

INTRODUCTION AND OVERVIEW (Caldwell and Nachtey) ........................................................................ 1-3

1.1 INTRODUCTION ................................................................................................................................. 1-3
1.2 EXPECTED CHANGES IN SOLAR UV RADIATION ............................................................................ 1-4
1.2.1. Basis for Expected Changes .............................................................................................................. 1-4
1.2.2. Solar UV-B Irradiance ...................................................................................................................... 1-5
1.3 IMPACTS OF ELEVATED UV-B RADIATION INTENSITIES ON THE BIOSPHERE ....................... 1-10
1.3.1 Avoidance of UV-B Radiation .......................................................................................................... 1-11
1.3.2 Tolerance of UV-B Radiation .......................................................................................................... 1-13
1.3.3 Response of Organisms to UV-B Radiation .................................................................................... 1-14
1.3.4 Evolution of Resistance .................................................................................................................. 1-24
1.3.5 Interactions ......................................................................................................................................... 1-26
1.4 CONCLUSIONS .................................................................................................................................. 1-27
References .............................................................................................................................................. 1-29
CHAPTER 2

POTENTIAL INCREASES IN UV RADIATION FROM STRATOSPHERIC FLIGHT

2.1 POTENTIAL DEPLETION OF THE OZONE COLUMN FROM STRATOSPHERIC FLIGHT
(HIDALGO) ........................................................................................................... 23

2.1.1 Unperturbed Ozone Column ........................................................................ 24
2.1.2 Perturbed Ozone Column ........................................................................... 24
2.1.3 General Circulation Models ....................................................................... 27
2.1.4 Stratospheric Circulation Models ............................................................... 28
2.1.5 Two-Dimensional Stratospheric Models .................................................. 29
2.1.6 One-Dimensional Stratospheric Models ................................................. 30
2.1.7 Results for the Unperturbed Ozone Column ............................................ 31
2.1.8 Results for the Perturbed Ozone Column .............................................. 32
2.1.9 Application of Results for the Ozone Column Decrease .......................... 32

2.2 EXPECTED CHANGES IN THE MIDDLE UV AND BIOLOGICALLY EFFECTIVE DOSES ...

2.2.1 The Middle Ultraviolet Reaching the Ground (GREEN, SAWADA and SHETTE) ..... 29
2.2.2 Multiple Scattering and Influence of Clouds, Haze and Smog on the Middle UV Reaching the
Ground (SHETTE, NACK and GREEN) ............................................................. 31
2.2.3 General Aspects of Dosimetry (NACHTWEY) ........................................... 32
2.2.4 Meares of Biologically Effective Radiation in the 280-340 nm Region
(GREEN and MILLER) .................................................................................. 33
2.2.5 Calculated Erythemal Radiation Doses (GREEN and MO) ...................... 33
2.2.6 Systematics of Climatic Variables and Implications—Local Erythemal Doses (MO and GREEN) ... 33

2.3 PENETRATION OF SOLAR ULTRAVIOLET RADIATION INTO TERRESTRIAL PLANT
COMMUNITIES (ALLEN, GAUSMAN and ALLEN) ............................................ 78

2.3.1 Solar Ultraviolet Radiation in Terrestrial Plant Communities ...................... 78
2.3.2 Factors Influencing Penetration of UV Radiation ...................................... 78
2.3.3 Modeling the Radiation Regime in Plant Communities ............................ 79

2.4 PENETRATION OF ULTRAVIOLET RADIATION INTO NATURAL WATERS (ZAMFELD) ... 108

2.4.1 Optical Properties of Natural Waters ....................................................... 108
2.4.2 Influence of Dissolved and Suspended Matter ........................................ 115
2.4.3 Interface Effects: Reflection and Refraction ............................................ 117
2.4.4 Minimum Absorption Values: Measured vs Calculated ............................ 118
2.4.5 UV-B and PAL Penetration into Various Water Types ............................. 125
2.4.6 The Influence of Solar Zenith Angle ....................................................... 128
2.4.7 Consideration of Phytoplankton ............................................................. 129

References ........................................................................................................... 159

Appendix A—Instrumentation for Absolute Solar and Global Ultraviolet Irradiance Measurements
(SUTHERLAND, DELIUSI and GREEN) .............................................................. 167

Appendix B—The Sunburn Unit for Comparison of Variation of Erythemal Effectiveness
(ROBBIE) ........................................................................................................ 202

Appendix C—Lamp Filter Systems for Simulation of Solar UV Irradiance Under Depleted Atmospheric Ozone
Concentrations (SUTHERLAND and DELIUSI) ................................................. 217

Appendix D—Field Measurements of Biologically Effective UV Radiation
(BERGER, ROBBIE and DAVIES) ..................................................................... 233

Appendix E—Measurements of the Penetration of Solar UV-B into Various Natural Waters
(CALHOUN) .................................................................................................... 234

Appendix F—Comparison of Germicidal Activity of Sunlight with the Response of a Sunburning Ultraviolet
Meter (HILL and BAGBY) .............................................................................. 235

Appendix G—Coordinated Experiments and Analyses of Ground-based Ultraviolet Irradiance
(MILLER, NOACK, SUTHERLAND, SCHWARTZ, FINDLEY, MCPETERS, BARBER and GREEN) .............................. 309

Appendix H—Penetration of Ultraviolet Radiation into Aquatic Ecosystems
(LORIENZI) ................................................................................................. 355

Appendix I—Erythema Radiation Doses (GREEN and MO) ............................... 363

Appendix J—Calculated Sunburn Responses (ROBBIE) ....................................... 367

Appendix K—Systematics of Climatic Variables and Implications—Local Erythemal Dose (MO and GREEN) ... 475

Appendix L—An Absolute Calibration of the Sunburn Meter (MO, CHAI and GREEN) .......................... 467
## Appendix M—Modified Dobson Erythema-UV Dosimeter Measurements
NOAA UV Radiation Monitoring Program (Machita, Cotton, Haas and Konihyr)

### CHAPTER 3

**GENERAL ASPECTS OF UV RADIATION EFFECTS ON BIOLOGICAL SYSTEMS**

### 3.1 GENERAL UV-RADIATION PHYSICS AND PHOTOBIOLOGICAL PRINCIPLES (Nachtwey)

- **3.1.1 The Photon and the Electromagnetic Spectrum**
- **3.1.2 Absorption of Photons**
- **3.1.3 Refraction, Reflection and Light Scattering**
- **3.1.4 Microscopic Aspects of Absorption**
- **3.1.5 Fate of Absorbed Energy in Molecules**
- **3.1.6 Fundamentals of UV Photobiology**
- **3.1.7 Terminology Used in Photobiology**

### 3.2 EFFECTS OF UV RADIATION ON NUCLEIC ACIDS (Murphy)

- **3.2.1 Chemical effects of UV Irradiation of Nucleic Acids**
- **3.2.2 Biological Effects of UV Irradiation of Nucleic Acids**
- **3.2.3 In Vivo Irradiation**
- **3.2.4 Evidence for Cellular Damage due to Nucleic Acid Alteration**
- **3.2.5 Summary and Conclusions**

### 3.3 GENETIC AND CHROMOSOMAL EFFECTS OF UV RADIATION (Nachtwey)

- **3.3.1 Mutations**
- **3.3.2 Chromosomal Aberrations**
- **3.3.3 Fate of Mutations and Chromosomal Aberrations in Nature**

### 3.4 LINKING PHOTOBIOLOGICAL STUDIES AT 254 NM WITH UV-B (Nachtwey)

- **3.4.1 Caldwell’s Generalized Action Spectrum Relating UV-B to 280 nm UV**
- **3.4.2 Linking 254 nm UV Effects to UV-B Effects via 280 nm UV Equivalents**
- **3.4.3 Use of the 254/280 Ratio as a Link Between 254 nm UV and UV-B Effects**
- **3.4.4 Experimental Test with Chlamydomonas**
- **3.4.5 Extension of Analysis to Other Organisms**
- **3.4.6 Error Analysis**
- **3.4.7 Conclusions**

### References

Appendix A—Comparative Effects of UV-B and 254 nm UV on the Alga, Chlamydomonas Reinhardt; Evidence for a Qualitative Difference (Nachtwey)

Appendix B—Dose Rate Effects in the UV-B Inactivation of Chlamydomonas and Implications for Survival in Nature (Nachtwey)

Appendix C—Inactivation of Dark-Repair Deficient Mutants of Escherichia Coli by Sunlight (Billen and Fletcher)

###CHAPTER 4

**PLANT RESPONSES TO UV RADIATION**

### 4.1 OPTICAL PROPERTIES: PENETRATION OF UV-B RADIATION INTO HIGHER PLANT TISSUE (Brabham and Biggs)

### 4.2 EFFECTS OF ULTRAVIOLET RADIATION ON MOLECULAR AND CELLULAR SYSTEMS OTHER THAN NUCLEIC ACIDS AND PHOTOSYNTHETIC SYSTEMS (Biggs and Campbell)

### 4.3 EFFECTS OF UV RADIATION ON COMPONENT PROCESSES OF PHOTOSYNTHESIS (Gerrard and Bradle)

### 4.4 ULTRAVIOLET-RADIATION-INDUCED ULTRASTRUCTURAL CHANGES IN PLANT CELLS (Campbell)
CHAPTER 5

RESPONSES TO UV RADIATION BY BACTERIA, ALGAE, PROTOZOA, AQUATIC INVERTEBRATES AND INSECTS

5.1 UV EFFECTS ON BACTERIA, ALGAE, PROTOZOA AND AQUATIC INVERTEBRATES (CALKINS and NACHTWEY) ................................................................. 53

5.2 RESPONSE OF MODEL ESTUARINE ECOSYSTEMS TO UV-B RADIATION (VAN DYKE and THOMSON) ................................................................. 58

5.3 EFFECTS OF UV RADIATION ON INSECTS (HSIAO) ................................................................. 59

5.3.1 Effects of UV Radiation on Insect Behavior .................................................................................. 59

5.3.2 Mutagenic and Cellular Effects of UV Radiation on Insects .................................................. 63

5.3.3 Developmental Effects of UV Radiation on Insects .................................................................. 67

References .............................................................................................................................................. 75
REFERENCES

Appendix A—Effects of Real and Simulated Solar UV-B Radiation in a Variety of Aquatic Micro-Organisms—Possible Implications for Aquatic Ecosystems (Calkins) ................................................................. 5-21

Appendix B—Natural Resistance of Freshwater Algae to UV Radiation—A Survey (McKnight and Nachtegael) ................................................................. 5-71

Appendix C—Phytoplankton Responses to UV Radiation and Ecological Implications of Elevated UV Irradiance (Lorenzen) ................................................................. 5-81

Appendix D—Response of a Simulated Estuarine Community to UV Radiation (Van Dyke and Thomson) ................................................................. 5-91

Appendix E—Experimental Studies of Effects of UV-B Radiation on Insects (Hsiao and Hsiao) ................................................................. 5-113

CHAPTER 6

NONHUMAN VERTEBRATE RESPONSES TO UV RADIATION

6.1 ULTRAVIOLET TRANSMISSION PROPERTIES OF VERTEBRATE TISSUES (Porter) ................................................................. 6-3

6.2 EFFECTS OF ULTRAVIOLET RADIATION ON VERTEBRATE DEVELOPMENT (Worrest and Kimeldorf) ................................................................. 6-15

6.2.1 Amphibians ............................................................................................................. 6-16

6.2.2 Fish ....................................................................................................................... 6-18

6.2.3 Reptiles ................................................................................................................. 6-18

6.2.4 Birds ..................................................................................................................... 6-18

6.2.5 Mammals ............................................................................................................. 6-19

6.2.6 Conclusions .......................................................................................................... 6-20

6.3 ASSOCIATION BETWEEN CANCER EYE AND SOLAR RADIATION (Macdonald) ................................................................. 6-20

Appendix A—Some Effects of UV-B Radiation (290–315 nm) on the Development and Survival of Toad Embryos and Larvae (Worrest and Kimeldorf) ................................................................. 6-23

References .................................................................................................................... 6-41

CHAPTER 7

BIOMEDICAL IMPLICATIONS OF UV CHANGES FOR MAN

7.1 OPTICAL PROPERTIES OF HUMAN SKIN (Daniels) ................................................................. 7-3

7.2 EFFECTS OF UV ON THE SKIN AND EYE

7.2.1 Erythema Effects on the Skin (Robertson and Urbach) ................................................................. 7-8

7.2.2 Acute Effects on the Eye (Urbach) ....................................................................................... 7-11

7.3 SKIN CANCER AND UV RADIATION

7.3.1 Experimental Production of Skin Cancer by UV (Urbach, Forbes and Blum) ................................................................. 7-13

7.3.2 Human Skin Cancer Production by UV (Urbach) ............................................................................. 7-19

7.3.3 Incidence of Nonmelanoma Skin Cancer (Urbach and Scotto) ................................................................. 7-22

7.3.4 Solar Radiation and the Etiology of Malignant Melanoma (Lee) ................................................................. 7-29

7.4 ESTIMATION OF EFFECT OF OZONE REDUCTION IN THE STRATOSPHERE ON THE INCIDENCE OF NONMELANOMA SKIN CANCER (Urbach, Davies and Berger) ................................................................. 7-42

7.4.1 Relationship of Ozone Layer Thickness to UV-B ............................................................................. 7-43

7.4.2 Estimated Effect of Increased UV-B on Skin Cancer (Basal Cell and Squamous Cell Cancer) ................................................................. 7-46

7.5 PROTECTION FROM DETRIMENTAL EFFECTS OF UV (Robertson and Daniels) ................................................................. 7-60

7.5.1 The Need for Protection ............................................................................................... 7-60

7.5.2 Natural ..................................................................................................................... 7-60

7.5.3 Conclusions ............................................................................................................. 7-63

7.6 MISCELLANEOUS DETRIMENTAL AND BENEFICIAL EFFECTS OF UV ON MAN (Daniels) ................................................................. 7-64

7.6.1 Miscellaneous Systemic Effects of UV ............................................................................. 7-64

7.6.2 Skin Aging .............................................................................................................. 7-65

7.6.3 Possible Beneficial Effects of UV ............................................................................... 7-65

7.6.4 Vitamin D and UV ................................................................................................... 7-66

References .................................................................................................................... 7-72
Appendix A—Ultraviolet Radiation From the Sun and Skin Cancer in Human Populations (Blum) .................................. 7 87
References ......................................................................................................................................................... 7 103
Appendix B—Biologic Effects of Stratospheric Ozone Decrease: a Critical Review of Assessments (Vander Leun and Daniels) ................................................................................................................................. 7 105
References ......................................................................................................................................................... 7 123
Appendix C—Ultraviolet, Ozone and Skin Cancer (Green and Mo) ........................................................................................................................... 7 125
References ......................................................................................................................................................... 7 139
Appendix D—Estimates of Increase in Skin Cancer Incidence with Time Following a Decrease in Stratospheric Ozone (Cutchis) ................................................................................................................................. 7 141
References ......................................................................................................................................................... 7 169

CHAPTER 8
PREDICTING EVOLUTIONARY RESPONSE OF NATURAL POPULATIONS TO INCREASED UV RADIATION (Antonovics)

8.1 COMPONENTS OF EVOLUTIONARY RESPONSE ......................................................................................... 8 7
8.2 EVIDENCE FOR EVOLUTIONARY RESPONSE TO UV RADIATION .......................................................... 8 10
8.3 PREDICTORS OF EVOLUTIONARY RESPONSE ......................................................................................... 8 13
8.3.1 Classical Neo-Darwinian Predictors ........................................................................................................... 8 17
8.3.2 Pre-Adaptational Characteristics .............................................................................................................. 8 17
8.4 CORRELATED RESPONSES AND AN ANALOGOUS EXAMPLE OF ENVIRONMENTAL CHANGE ............... 8 20
8.5 PROGNOSIS AND SUMMARY ...................................................................................................................... 8 22
References ......................................................................................................................................................... 8 23

CHAPTER 9
ERROR AND SENSITIVITY ANALYSIS OF ESTIMATED BIOLOGICAL RESPONSES TO ULTRAVIOLET PERTURBATION (Schainker and Lau)

9.1 DEFINITION AND CHARACTERIZATION OF UNCERTAINTIES IN THE CIAP STUDY .................................. 9 3
9.1.1 Measurement Uncertainties ....................................................................................................................... 9 4
9.1.2 Model Validation Uncertainties ................................................................................................................. 9 5
9.1.3 Model Parameter Uncertainties ................................................................................................................. 9 5
9.2 SENSITIVITY AND STATISTICAL UNCERTAINTY ANALYSES ................................................................ 9 5
9.2.1 UV Radiation Penetration Into Plant Canopies .......................................................................................... 9 6
9.2.2 Erythemal Dose vs Surface UV Radiation .............................................................................................. 9 6
9.2.3 Skin Cancer Effects vs Ozone Reduction and UV-B Radiation Changes .................................................. 9 7
References ......................................................................................................................................................... 9 13

CHAPTER 10
MONITORING FOR EFFECTS OF STRATOSPHERIC AVIATION—BIOSPHERIC IMPACT AND ASSESSMENT (MESA III)

10.1 MESA PROGRAM (Marmo and Pressman) ................................................................................................. 10 3
10.1.1 Introduction ............................................................................................................................................... 10 3
10.1.2 Monitoring Phases ................................................................................................................................... 10 5
10.1.3 MESA Operations Plan ........................................................................................................................... 10 5
10.2 INVOLVEMENT OF BIOLOGICAL SYSTEMS IN A MONITORING PROGRAM (Caldwell and Nachtewey) .......................................................................................................................... 10 8
10.2.1 Biological Perspective .............................................................................................................................. 10 9
10.2.2 Biological Systems as Monitoring Instruments ...................................................................................... 10 15
10.2.3 Causality ................................................................................................................................................. 10 18
10.2.4 Conclusions and Recommendations ...................................................................................................... 10 19
References ......................................................................................................................................................... 10 21
INTRODUCTION AND SUMMARY

Summary

IMMUNOLOGICAL CHANGES CAUSED BY ULTRAVIOLET RADIATION

Introduction

Studies on Experimental Animals

Studies on Humans

Implications of Increasing UV-B Radiation

Research Recommendations

NONMELANOMA SKIN CANCERS IN HUMANS

Research Recommendations

MALIGNANT MELANOMA IN HUMANS

Incidence and Mortality Data

Evidence for the Role of Sunlight

Evidence Against the Role of Sunlight

Malignant Melanoma in Animals

Implications

Research Recommendations

ANIMAL STUDIES OF PHOTOCARCINOGENESIS

Dose Response Relationships

Time Dose Reciprocity

Action Spectra

Wavelength Interactions

Research Recommendations

MOLECULAR AND CELLULAR STUDIES

Mechanisms of UV-B-induced Damage

Z-DNA Photochemistry

Chemical Structure of DNA Photoproducts

Nontargeted Mutagenesis

Sensitive Assays for DNA Damage

Role of Membrane Photooxidation

Research Recommendations

EFFECTS OF UV-B RADIATION ON PLANTS AND VEGETATION AS ECOSYSTEM COMPONENTS

Introduction

Natural UV-B Environment and Adaptations to it by Plants

Effects of Increased UV-B Irradiance on Plant Growth and Structure

Effects of UV-B Irradiance on Water Balance and Photosynthesis

Effects of UV-B Radiation on Flowers, Pollination and Production of Seeds

Effects of Ultraviolet Radiation on Competition and Interactions Within Ecosystems

Solar UV-B Radiation and Evolution

Research Recommendations

EFFECTS OF UV-B RADIATION ON MARINE ORGANISMS

Introduction

Penetration of UV Radiation in the Ocean

Effects on Phytoplankton and Primary Production

Effects on Invertebrates

Effects on Fish Larvae

Research Recommendations

REFERENCES, PART II