EFFECTIVE UV RADIATION FROM MODEL CALCULATIONS AND MEASUREMENTS

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ABSTRACT

Model calculations have been made to simulate the effect of atmospheric ozone and geographical as well as meteorological parameters on solar UV radiation reaching the ground. Total ozone values as measured by Dobson spectrophotometer and Brewer spectrometer as well as turbidity were used as input to the model calculation. The performance of the model was tested by spectroradiometric measurements of solar global UV radiation at Potsdam. There are small differences that can be explained by the uncertainty of the measurements, by the uncertainty of input data to the model and by the uncertainty of the radiative transfer algorithms of the model itself. Some effects of solar radiation to the biosphere and to air chemistry are discussed. Model calculations and spectroradiometric measurements can be used to study variations of the effective radiation in space and time. The comparability of action spectra and their uncertainties are also addressed.

1. INTRODUCTION

Solar UV radiation affects the biosphere, some types of materials and the chemistry of atmospheric trace gases (UNEP 1989, 1991). Due to its dependence on atmospheric ozone, cloudiness and turbidity natural and anthropogenic variations of those parameters can affect the diversity of living species, the air quality in the planetary boundary layer and the climate of the earth. For effects with known action spectra the effective radiation can be determined from model calculations and/or measurements of the spectral distribution of solar radiation.

2. MODEL CALCULATION OF THE EFFECTIVE SOLAR UV RADIATION

A modified version of the radiation model by Green et al. (1974 a, b, 1980) and Schippnick and Green (1982) has been applied to simulate solar UV radiation falling on a horizontal or spherical plane in the UV region using a stepwidth of \( \Delta \lambda = 1 \) nm. Depending on location and time of the year, solar zenith angles and distances between the earth and the sun were determined from the algorithms given by Sonnige (1989). The extraterrestrial radiation was taken from CIMO (1981), corresponding to a solar constant of 1367 W m\(^{-2}\), and the ozone absorption coefficients from Bass and Paur (1985). Values of the effective radiation \( E_r (\Theta, z, A) \) for an effect X were determined by

\[
E_r (\Theta, z, A) = \int e (\lambda) E (\lambda, \Theta, z, A) d\lambda
\]

(\( \lambda \): wavelength, \( \Theta \): solar zenith angle, \( z \): height, \( A \): surface albedo, \( e (\lambda) \): optical depth of aerosol and gaseous absorbers.)

3. MEASUREMENTS OF SOLAR RADIATION

A spectrometer OL 752/10 (Optronic Laboratories) was used for measurements of solar radiation at Potsdam. The instrument is a double monochromator with dual holographic gratings that allow a spectral resolution of 1.5 nm to 10 nm halfwidth. The spectrometer was calibrated by a 200 W tungsten filament lamp, which is absolutely calibrated against an Eppley Standard Cell at the National Institute of Standards and Technology (NIST).
spectroradiometric accuracy of the calibration relative to NIST is
given as \( \pm 2\% \). Due to a straylight problem below 295 nm
radiance values with \( \lambda < 295 \) nm had to be extrapolated from
radiances measured at higher wavelengths. The spectrometer was
placed on the tower roof platform of the Observatory at a height of
18 m above the ground. A spectral resolution of 1.5 nm was
selected with a stepwidth of 2 nm. Fig. 3 shows a spectrum
measured on October 11, 1991. The time of measurements
soresponds to a solar zenith angle of around 60°. Also shown in
Fig. 3 is the result of the model calculation for the respective zenith
angle. Atmospheric total ozone, which is needed as input to the
model, was taken from measurements with a Dobson
spectrophotometer (ADDSS) and a Brewer spectrometer (DS) at
Potsdam. The measured ozone value was decreased by 2.7 % to
account for the inadequate ozone absorption coefficients that were in
use before January 1, 1992 (Hudson et al. 1991). The model
calculation is thus in two ways based on the Basa and Pear (1985)
ozone absorption coefficients. It can be seen from Fig. 3 that the
correspondence between model calculation and measurement is quite
good.

<table>
<thead>
<tr>
<th>Erythemal radiation (W m(^{-2}))</th>
<th>Rel. to BGBl. (1987)</th>
<th>Reference of action spectrum</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.0194</td>
<td>0.69</td>
<td>Coblenz and Stair (1934)</td>
</tr>
<tr>
<td>0.0171</td>
<td>0.60</td>
<td>Berger et al. (1968)</td>
</tr>
<tr>
<td>0.0257</td>
<td>0.91</td>
<td>Cripps and Ramaswamy (1970)</td>
</tr>
<tr>
<td>0.0159</td>
<td>0.56</td>
<td>Komskry &amp; Machta (1973)</td>
</tr>
<tr>
<td>0.0188</td>
<td>0.66</td>
<td>DIN (1979)</td>
</tr>
<tr>
<td>0.0283</td>
<td>1.00</td>
<td>BGBl (1987)</td>
</tr>
<tr>
<td>0.0266</td>
<td>0.94</td>
<td>Photocarcinogenesis (CIE 1986)</td>
</tr>
</tbody>
</table>

Table 1: Erythemal radiation determined for a spectrum of measured solar global radiation, \( G = 59.63 \) W, \( O_3 = 271 \) D

However, the uncertainties in the effective radiation depend both on
the uncertainties in the measured and modelled solar radiation, and
on the uncertainties of the action spectrum. As an example, Table 1
shows the erythemal radiation determined from one spectrum of
solar global radiation (cf. Fig. 3), but using erythemal action spectra
from different sources. For comparison, the last row in Table 1
shows the result for the photocarcinogenesis. It can be seen that the
radiation producing photocarcinogenesis is closest to the latest
erythemal action spectrum used (BGBl 1987). The different shapes
of the action spectra of the erythemal effect do not only provide
different absolute values of the erythemal radiation, but do also
produce different dependencies of the effective radiation on
atmospheric ozone. If model calculations and measurements are to
be compared, there must be a consensus on the action spectra
applied. The model has been used to simulate variations of the
effective radiation in space and time. As an example, Table 2 shows
the percentage ratios of daily totals of UV radiation on June 21,
September 23, and December 21, referred to March 21, at the
station Arkona. Seasonal averages of total ozone (March: 400 D,
June: 360 D, September: 310 D, December: 320 D) and typical
surface albedo values of 5 %, 1 %, 5 %, 5 % (grassland) and 60 %
(snow) were used as representative input values. While UV and
UVA radiation, which are nearly independent on atmospheric ozone,
show a seasonal variation from 20 % to 200 % of the spring time
value, the seasonal variations of those effects that are strongly ozone
dependent are much higher. They extend from 6 % (winter) to 402
% (summer) for the UVB radiation up to the range 2 % to 950 % of

<table>
<thead>
<tr>
<th></th>
<th>June 21</th>
<th>Sept. 23</th>
<th>Dec. 21</th>
</tr>
</thead>
<tbody>
<tr>
<td>UV (( \lambda &lt; 400 ) nm)</td>
<td>219</td>
<td>101</td>
<td>18</td>
</tr>
<tr>
<td>UVA (( 315 &lt; \lambda &lt; 400 ))</td>
<td>217</td>
<td>100</td>
<td>19</td>
</tr>
<tr>
<td>UVB (( \lambda &lt; 315 ) nm)</td>
<td>402</td>
<td>140</td>
<td>6</td>
</tr>
<tr>
<td>Erythema (DIN 1979)</td>
<td>488</td>
<td>154</td>
<td>6</td>
</tr>
<tr>
<td>Photocarcinogenesis (CIE 1986)</td>
<td>499</td>
<td>156</td>
<td>6</td>
</tr>
<tr>
<td>Bactericide (DIN 1979)</td>
<td>716</td>
<td>192</td>
<td>3</td>
</tr>
<tr>
<td>Pigmentation (DIN 1979)</td>
<td>221</td>
<td>101</td>
<td>18</td>
</tr>
<tr>
<td>Plant response (Caldwell 1971)</td>
<td>606</td>
<td>178</td>
<td>3</td>
</tr>
<tr>
<td>Conjunctivitis (DIN 1979)</td>
<td>930</td>
<td>229</td>
<td>2</td>
</tr>
<tr>
<td>Phytopathitis (DIN 1979)</td>
<td>385</td>
<td>136</td>
<td>7</td>
</tr>
<tr>
<td>Yellowing of PVC (Andrady and Scarle 1989, Andrady et al. 1989)</td>
<td>244</td>
<td>105</td>
<td>15</td>
</tr>
</tbody>
</table>

Table 2: Percentage ratios of daily totals of solar global radiation for different effects at the station Arkona (54° 41′ N, 13° 26′ E) on June 21, September 23, and December 21, referred to March 21.

The spring time value for photocytotoxicity. This phenomenon is
similarly reflected in the spatial changes of the radiation effects that
can be expected as a result of changes in the total ozone
concentration. Fig. 4 shows the modelled percentage increase in
zonal averages of UVB radiation and in photoconjunctivitis radiation
for a global uniform reduction of total ozone by 10 %. In the first
model run (no change), the average latitudinal ozone distribution
from London et al. (1976) was used. The vertical distribution of
ozone is not changed in the calculation, because such a change could
produce different results (Brühl and Crutzen 1989). While the
latitudinal gradient for UVB is between 10 % in the tropics to around 30 % at high latitudes in winter, for the photoconjunctivitis,
which is highly ozone dependent, the range of changes is between
32 % in the tropics to 60 % at high latitudes. It must be noted here
that the absolute increase in the effective radiation attains its
maximum value in the tropics, where the normal radiation levels are
highest. On the other hand, the extent to living matter depends on
how much additional effective radiation can be tolerated by the
individual species and how they are capable of adapting to it.

4. CONCLUSION

Effects of solar radiation to the biosphere can be studied both by
model calculations and measurements. The uncertainties in both
approaches do not only arise from inaccurate algorithms,
uncertainties of the input parameters to the radiation model and
measurement errors, but also from the uncertainties of the action
spectra, which describe an "average" or typical behaviour of an
individual or a group of species under definite conditions. The
different types of erythemal action spectra, which produce different
values of erythemal radiation, are an example of the increasing
knowledge about radiation effects to human skin. Despite the deficiencies of the approach to use model calculations and spectroradiometric measurements for estimating the effective radiation, they provide an opportunity to study the effects of solar radiation and its changes to different kinds of living species as well as on air chemistry.

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RADIATION AMPLIFICATION FACTORS

THETA=60°, IT=6, A=5 %, CLEAR SKY

Fig. 1 Radiation amplification factors for biologically effective radiation at the earth’s surface in dependence on the total ozone value (DNA: DNA absorption, Sutherland and Griffin 1981; UVB: λ < 315 nm; ERY: erythema radiation; PHC: photocarcinogenesis; CON: photoconjunctivitis; KER: photokeratitis; BAC: bactericide effect; PLR: plant response). Solar zenith angle: 60°, surface albedo: 5 %, clear sky.

Fig. 2 Photolysis rate of ozone [10⁴ s⁻¹] in dependence on total ozone for a solar zenith angle of θ = 60°, surface albedo of 10 %, cloudless conditions and low turbidity
Fig. 3  Solar global radiation at Potsdam (52° 22' N, 13° 5' E) on October 11, 1991, 11.24 CET, $\theta = 59.631^\circ$  
$\circ\rightarrow\circ$ extraterrestrial radiation from CMIO (1981) corrected for solar zenith angle and distance sun-earth  
$\rightarrow$ measurements of global solar radiation taken with the spectrometer OL 752/10 at Potsdam 18 m above the ground, clear sky  
$\circ\rightarrow\circ$ model calculation of global radiation (direct + diffuse) with $O_3 = 271$ D and an aerosol optical thickness of $\tau = 0.4$ with $\lambda = 350$ nm

Fig. 4  Litudinal and seasonal percentage change of UVB ($\lambda < 315$ nm) (a) and photococonjunctivistic (b) radiation modelled for a uniform reduction of total ozone by 10 %