Surface erythemal irradiance and total column ozone above Durban, South Africa, for the period 1996–1998

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This is the first presentation of UV irradiance measurements at Durban for a sequence of three years, namely 1996, 1997 and 1998. A Yankee Environmental Systems pyranometer was used to record erythemal irradiance at 10-minute intervals throughout these years, with total downtime of just a few weeks. From this database we have extracted noon and clear sky, constant solar zenith angle data. Of the latter type, curves showing the deviation of individual years from 3-year averages are discussed. TOMS satellite ozone data for Durban show, as expected, an anticorrelation between ozone and UV irradiance values. Another factor influencing the UV irradiance seems to be particulate pollutants, to which we attribute the low winter 1998 readings. The data otherwise show a good year-to-year consistency.

Introduction

Solar ultraviolet radiation in the UVB region (280–320 nm) causes damage to humans such as reddening of the skin (erythema) and skin cancer (melanoma). Damage is also caused to plants and plankton, the latter being a key link in the aquatic food chain. Most of the direct solar ultraviolet irradiation is shielded by atmospheric ozone, which has an absorption line in that spectral region. Hence, a decrease in ozone abundance will increase the ultraviolet radiation received on the ground, resulting in enhanced damage. In New Zealand, for example, a 1% decrease in ozone will result in a 3% increase in the number of reported cases of melanoma skin cancer. Hence, there is a need for long-term monitoring of UV irradiance at many locations.

Biologically active irradiance constitutes those wavelengths incident on the earth’s surface that are harmful to living organisms. It is obtained by modifying the measured UV irradiance by a weighting function or action spectrum. An action spectrum is defined as a plot of the relative effectiveness of radiation of different wavelengths to produce a given biological effect, that is, it quantifies the response of the system to UV radiation. Action spectra have been determined for plants, phytoplankton, structural DNA damage and carcinogenesis in animal cells. The erythemal response spectrum is the action spectrum for the induction of human erythema. Integration under this curve gives the total erythemal irradiance (W m⁻²), which is the energy per unit area that will actively harm human skin as indicated by reddening of the skin sometime after the completion of UV exposure. Division of this erythemal irradiance by 25 mW m⁻² yields the so-called UV index, which has been generally adopted as a measure of erythemal (skinburning) UV irradiance. It is non-dimensional and was chosen to give the typical sea-level UV index values in Table I, which also shows the corresponding sunburn times (maximum permissible exposure). UV index values above 7 must be regarded as dangerous. Our data set shows that values in this range are reached at Durban throughout the year with the exception of the time around the winter solstice. In summer, however, values in the extreme category are the norm and peak values well beyond 10 are measured.

Ozone above Antarctica became a focal point of atmospheric research since Farman et al. reported a startling 50% springtime decrease in ozone beginning in late September to early October, now known as the annually recurring Ozone Hole. After formation in October, the ‘hole’ expands towards South Africa, which experiences a ridge of enhanced ozone near the edge of the hole. In 1988, for example, the average October and December TOMS total column ozone values were 308 DU and 282 DU (Cape Town); 298 DU and 278 DU (Durban); 288 DU and 268 DU (Pretoria). At each location there is a decrease of about 20 DU in total ozone when the ozone hole dissipates. Increasing ozone with decreasing latitude is a characteristic feature at these latitudes. To our knowledge there are only three UV monitoring stations in South Africa from which to establish long-term changes. In this paper, we present measurements taken at Durban (29°52’S, 30°59’E; altitude approximately 150 m), over three consecutive years (1996–1998). Duigan et al. presented UVB data measured at Durban for the period February to December 1993. The seasonal variation of noon erythemal sunburntimes exhibited a minimum (9.6 min) and maximum (44.5 min) during February to December, and in June, respectively.

Data acquisition and processing

A Yankee Environmental Systems (YES) pyranometer measures integrated UVB irradiance for the 280–320 nm waveband. This is the power per unit area of UVB radiation incident on a horizontal surface and received from the entire hemisphere of the sky. Global UVB irradiance is the sum of the direct and diffuse components. Raw YES data are in the form of a voltage recorded every 10 minutes which, with the use of an appropriate correction factor, may be converted to integrated UVB irradiance (280–320 nm) or integrated erythemal irradiance (280–330 nm), weighted by the Diffey erythemal action spectrum. Daily integrated UVB and erythemal irradiances are interpolated to obtain values at solar zenith angles (SZAs) of 25°, 35°, 45°, 55°, 65° and 75°. This is done in order to investigate typical fluxes for these solar elevations and also the effect of variations in total column ozone on solar irradiance.

For any location, surface UV flux is a function of SZA, cloud cover and total column ozone. During cloudy conditions, UV irradiance may be attenuated by up to 50%, but partially cloudy conditions may enhance UV irradiance by up to 20% owing to scattering processes. It was therefore necessary to separate data recorded under cloudy conditions from the clear sky data set. Only clear sky data are analysed here in order to discover a possible lower bound on erythemal burntimes. Clear sky data were identified by calculation of a ‘cloud ratio’. Theoretical integrated erythemal UV irradiances were calculated with the aid of the SPIRE surface irradiance model in which a constant extraterres-

Table 1. The UV index: the columns represent the widely accepted definition of four danger categories and the sunburn time (maximum permissible exposure) for a Caucasian skin.

<table>
<thead>
<tr>
<th>UV Index</th>
<th>0–3.9</th>
<th>4–6.9</th>
<th>7–8.9</th>
<th>&gt;9</th>
</tr>
</thead>
<tbody>
<tr>
<td>Category</td>
<td>Sunburn context</td>
<td>Low</td>
<td>Moderate</td>
<td>High</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;1 h</td>
<td>About 30 min</td>
<td>About 20 min</td>
</tr>
</tbody>
</table>

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trial solar irradiance mediated by the changing earth–sun distance is assumed. Model inputs include extraterrestrial irradiance, ozone absorption cross section, total column ozone, location and day number. For the selected SZAs, the ratio of the observed to theoretical irradiances was calculated; this was termed the ‘cloud ratio’. Low cloud ratio values (below 0.85) characterized cloudy conditions and these data were omitted.

**Observations**

The main factors influencing surface UV irradiance received on a horizontal surface are the SZA, which determines the optical path length through the atmosphere, cloud cover and total column ozone. Less important factors are aerosol loading of the atmosphere, the sun–earth distance and altitude/air pressure. Figure 1 shows the Durban daily noon erythemal irradiance, during 1997, for all days that were clear and cloud-free. A common feature of such graphs is an upper envelope that gives a top limit for the scatter of data due to cloud. This envelope has approximately the shape of a cosine curve. It represents what could be called the clear sky limit of irradiance, that is, for a given SZA the maximum irradiance measured when the sky is clear. Clouds can reduce the values by up to almost 100%. Hence the measured irradiance can be any value below the envelope, depending on cloud cover. The shape of the envelope is determined by the seasonal variation of the SZA, which is approximately cosine shaped. In Fig. 1, for example, the lowest values are observed at midwinter (day 172, 1997). Very few data points are above the envelope, which is indicated by a solid line (see around day 290, 1997). Such values are measured when sunlight breaks through a gap between clouds, which acts as a waveguide.

Figure 2 shows 30-day running-average curves for clear sky noon UV index readings; one for each year from 1996 to 1998. The curves visualize the clear sky envelope. They track each other closely with the exception of the periods around day 300, where the 1997 curve is about 20% above the other two, and day 200, where the 1998 curve is about 20% below the other two. The reason for the latter could be high atmospheric aerosol loading due to an exceptionally dry winter. The former could be caused by lower ozone values. The ozone value for the time concerned in 1997 was about 290 DU, roughly 10 DU below the three-year average (1996–1998).

Seasonal variations of the irradiance as seen in the noon values of Fig. 1, or any other constant time plot, can be offset by...
Fig. 4. Deviation of constant-SZA irradiance from the three-year average for individual years (30-day running average). Systematic differences between years are most pronounced during the winter months.

constant SZA plots: for each day of the year, data from a different time of day are chosen; for instance, in winter later in the morning or earlier in the afternoon to represent the same SZA throughout the year. Figure 3 shows plots for the year 1997 for constant SZAs of 65°, 75° and 85°. TOMS satellite ozone data have been plotted along with the irradiance. For clarity we have omitted the readings affected by cloud cover. Having thus excluded influences of season and weather, the data are dependent on only two factors, namely absorption by aerosol pollutants and ozone (both surface and stratospheric). On this graph, as well as in the remaining figures, the erythemal irradiance is given in UV index units (see Table 1). The correlation coefficients for TOMS and irradiance data are −0.25, −0.19 and 0.01 for the SZAs 65°, 75° and 85°, respectively. This means that an anticorrelation is observed and becomes more pronounced for lower SZAs. It is understandable that no correlation is visible for high SZAs because of the low signal, the cosine error and possible physical obstructions of the instrument. The slight increase in ozone from about 250 DU during the first six months of the year to about 300 DU in spring (about day 250 to 300) corresponds to a fall in irradiance values at that period. This decline can also be seen for the SZAs of 65° and 75°. The 85° SZA curves have values too close to the instrument error to be analysed in detail. The depression is due to the well-known fact that ozone is a UV absorber. However, somewhat surprising is the recovery of irradiation readings to values above the early-year average, as the ozone readings start to decrease again (day 300).

One should compare the annual variation of ozone abundance above Durban with the situation in the Antarctic, where the Ozone Hole forms at the same time that the slight enhancement is observed at Durban.

In the following, we present the data as running average plots to smooth out statistical fluctuation and to achieve a clearer picture. Seven-day running averages for ozone and 30-day running averages for irradiance data have been chosen throughout. The selection was made to achieve a stable curve with as little averaging as possible.

Figure 4 shows the deviation of the irradiation for an individual year from the three-year average. These measurements are for a constant SZA of 65°. There seems to be little deviation (less than 0.05 UV index units) from the average, with the following exceptions, namely, around the end of the year (after day 300), more pronounced fluctuations were observed. In particular, years 1997 and 1998 differed by about 0.5 UV index units around day 320. The reason could be that this was the time of enhanced ozone abundance (see above), which was more pronounced in 1998 than in 1997. The main feature, however, appears to be the gap of about 0.1 UV index units between the winter values of 1998 and 1997 which formed over a period of more than 100 days, namely, days 140–260. This is clear evidence for the unusually low winter readings in 1998 (see above). Instrument downtime in 1996 shows as a data gap (days 150–200). Nevertheless, with average values of about 1.5 UV index units, there is good consistency between the three years.

Conclusion

It is interesting to compare the clear sky noon erythemal UV indices of 1998 with those obtained by Duigan et al. for 1993. For a UV index peak (near day 45) followed by a UV index trough (near day 200), the UV indices are 12 and 2.8 in 1993 compared to 13 and 3 in 1998. The consistency of these data sets is impressive but needs further testing over a period of about 10 years. A year-to-year consistency of the observations is also evident in the plots of deviation from the 3-year-average.

Correlation coefficients at SZAs 65°, 75° and 85° for TOMS ozone and UV irradiance measurements indicate an anticorrelation that is more pronounced for smaller angles.

Near day 45, in February 1998, the peak UV index of 13 was reached. The latter is an extreme result corresponding to sunburn times of less than 15 minutes. Such levels pose a threat to residents, many holiday visitors and to the local environment.

Although the UV irradiation levels have shown some consistency on a year-to-year basis between 1996 and 1998, it is essential that this consistency be checked for a much longer period.

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