CLIMATOLOGY OF UVB AND OZONE VARIATIONS & THE GLOBAL SOLAR UV-INDEX

C.R. Roy , H.P. Gies and S.J. Toomey
Australian Radiation Laboratory, Lower Plenty Road, Yallambie, Victoria, Australia 3085

INTRODUCTION

Human overexposure to solar ultraviolet radiation (UVR) can result in acute and chronic adverse health effects on both the skin and the eye. Skin cancer (both non-melanoma and malignant melanoma) and cataract impose a huge social and cost burden on many societies throughout the world. Such human health problems can be avoided if the individual reduces their UVR exposure. Unfortunately enlightenment may not help persons who have experienced high episodic exposures during childhood as this appears to be an important causal factor in melanoma. In some countries public educational campaigns have been underway for decades in other countries they are just beginning; the global solar uv-index provides a globally consistent means of reporting or predicting UVR as part of public education on UVR exposure. There are now indications that some of these programs have been effective in halting the climb in melanoma incidence.

The UVR, and in particular UVB, reaching the earth's surface varies with both latitude and time (both of the day and year). The transmission of the extraterrestrial radiation through the atmosphere is determined by ozone, clouds, aerosols and to a lesser extent, trace gases. In recent decades there has been considerable concern that long-term changes in ozone and perhaps clouds and aerosols may result in changes in the UVB at the earth's surface.

Atmospheric attenuation of solar UVR

The extraterrestrial solar spectrum is rich in UVC (200-280 nm), UVB (280-315 nm) and UVA (315-400 nm). However passage through the atmosphere removes the UVC and most of the UVB component. This reduction is due mainly to absorption by ozone and molecular scattering. The amount of transmitted UVB is sensitive to even small changes in the ozone column (see Figure 1).

The spectral irradiance can be calculated for different total ozone amounts using an ARL-modified version of the Björn model (1). The decrease in the ozone column from 300 to 270 DU results in the UVB increasing by 95%, 20% and <5% for the wavelengths of 295, 305 and 315 nm, respectively. Overall this 10% decrease in ozone results in about a 10% increase in total UVB (280-315 nm).

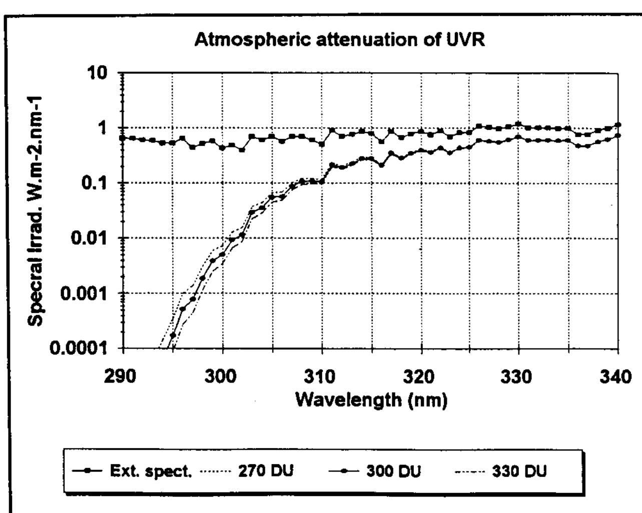


Figure 1
Spectral irradiance at the earth's surface for clear skies, a SZA of 5° and for three different ozone columns. Also shown is the extraterrestrial spectral irradiance.

Solar zenith angle (SZA)

The SZA describes the angle between the local vertical direction and the direction of the solar disk. The smaller the SZA, the less atmosphere the solar radiation must pass through and hence the greater the solar UVR (see Figure 2). The SZA varies with time of day and year and with latitude. Only within the tropics is a SZA of 0° attainable (as the sun passes overhead).

For a given ozone column (here 270 DU) the total UVB for SZA=35° is 64% of its value at SZA=5°. At 70° the corresponding value has dropped to 6.4%. For total UVR the effect is less with values of 77% (35°) and 23% (70°) obtained for the two examples.

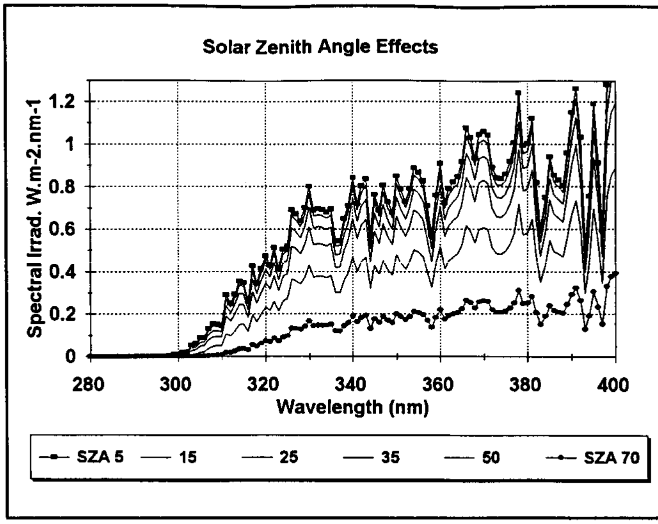


Figure 2.
The effect of changing SZA on the spectral irradiance at the earth's surface.

Total ozone

Stratospheric ozone is produced by the photolysis of oxygen molecules by short-wavelength solar UVR (wavelengths <242 nm). Ozone is formed largely in the equatorial regions and it is transported polewards. The amount of ozone is determined by the dynamic balance between the production and several catalytic destruction cycles and by transportation processes. Ozone depletion concerns in recent decades result from a man-made chlorine destruction cycle.

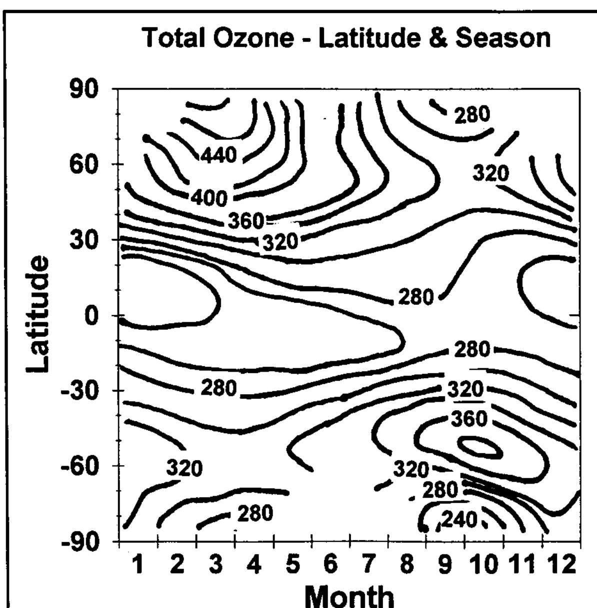


Figure 3.
Indicative latitudinal and monthly variation of total ozone (DU). Values are averages for the years 1979-89 from the TOMS satellite data (2).

Ozone depletion

Both satellite and Dobson ground-based measurements show decreases of total ozone in winter in the Northern Hemisphere. There is evidence of significant decreases in spring and summer in both the Northern and Southern Hemispheres at middle and high latitudes. There is no evidence for any significant trends in the tropics. Throughout the 1980s and 1990s there have been deep and extensive ozone holes in the southern spring.

Table 1.
Total ozone trends in units of percentage change per decade (3).

Season	45°S	TOMS Data: 1979-91 Equator	45°N
Dec-Mar	-5.2	+0.3	-5.6
May-Aug	-6.2	+0.1	-2.9
Sep-Nov	-4.4	+0.3	-1.7

The analysis shown in Table 1 indicates that little or no depletion has occurred in the equatorial region and at 45°N the greatest depletion occurs during winter when solar UVB is at its lowest. At 45°S significant depletion occurs all year with summer only slightly less than winter.

Effective UVR: computed and measured

The biological effectiveness of ultraviolet radiation is very wavelength dependent with UVB being considerably more biologically effective than UVA radiation. Within the UVB, between 300 and 315 nm, the relative spectral effectiveness decreases by three orders of magnitude which means that spectral measurements within this region must be very precise or large errors in the calculated effective radiation will result. The erythemal response curve of the International Commission on Illumination (4 and Table 2) is used to weight the spectral irradiance distribution.

Table 2
CIE erythemal effectiveness function.

Effectiveness function (S_λ)	Wavelength region (nm)
1.0	$250 \le \lambda \le 298$
$10^{0.094(298-\lambda)}$	$298 \le \lambda \le 328$
$10^{0.015(139-\lambda)}$	$328 \le \lambda \le 400$

The amount of UVR required to induce sunburn or erythema in normal human skin is usually designated as the minimum erythemal dose (MED). Using the CIE erythemal effectiveness function, the MED for skin type I, the most sensitive type (skin that always burns and never tans), is approximately 200 J m^{-2} (5).

The monthly average daily erythemal UVR for Melbourne (37.8°S) is shown in Figure 4 for six of the years between 1986 and 1993. The general shape is typical of a mid-latitude site and is determined by the SZA variation over the year. The annual total MEDs are also given. The average annual total is 4160±270 (SD). Year-to-year differences are due largely to variations in cloud cover and total ozone.

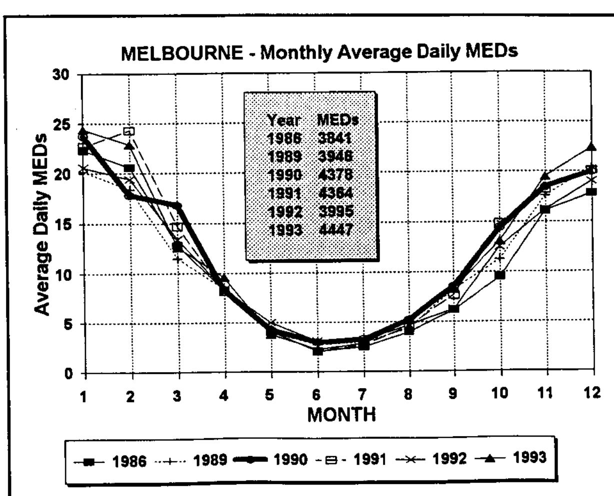


Figure 4. Variation of the total mean erythemal UVR (in MED units) for Melbourne in the years indicated.

The global distribution of erythemal irradiance can be calculated (3) and this is shown in Figure 5. The patterns are as expected with very high and relatively constant values throughout the equatorial and tropical regions. In the mid-latitudes the values are high in summer but are very low in winter. The high levels in Antarctica as a result of the ozone hole are not represented in this plot.

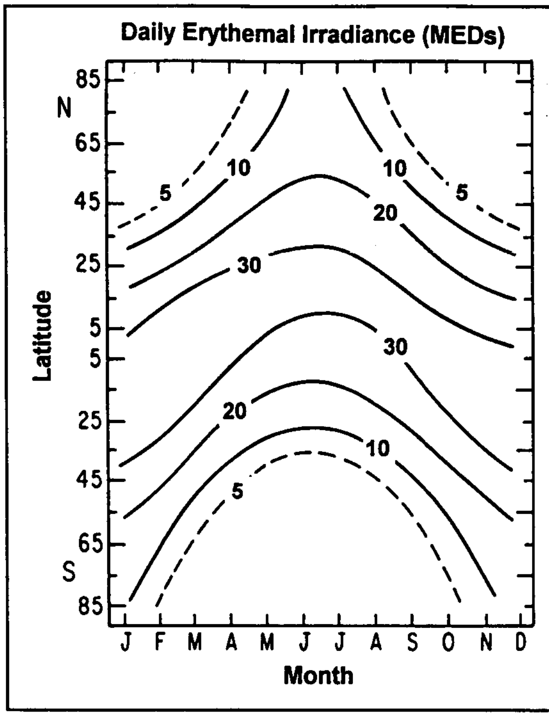


Figure 5. Latitudinal and monthly distribution of integrated daily erythemal irradiance in units of MEDs. Computed for clear skies and based on TOMS zonally averaged total ozone for 1980 (3).

Measurements and calculations have been made of erythemal or effective UVR for a number of locations in both the Northern and Southern Hemisphere and some of these are shown in Figure 6. The results are consistent with the data presented in Figure 5. The results for the southern hemisphere (6) are measurements and hence include the effect of cloud cover which can be quite significant; for example, during the tropical 'wet-season'. The high latitude results (9) are measurements from Finland. The more recent results of Seckmeyer et al.(10) agree largely with Figure 5 but also illustrate the impact of the Antarctic ozone hole on the southern hemisphere results.

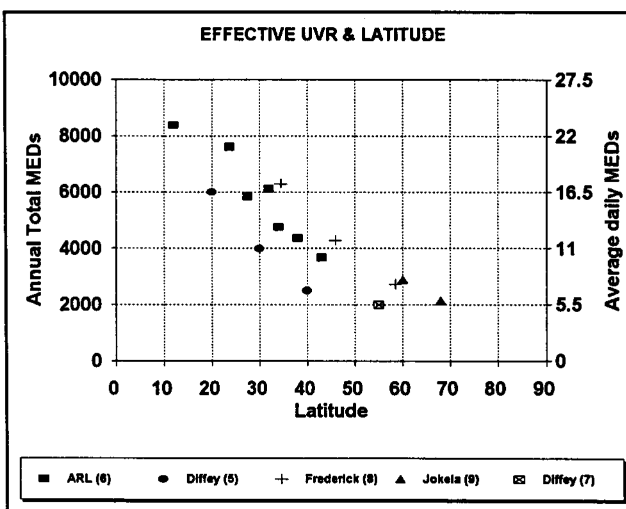


Figure 6. Measured effective UVR during the years 1989-1991. The results for the NH and SH are not differentiated on the plot.

Erythemal UVR and clouds

The transmission of UVR through clouds is a function of the optical depth. Solar UVR transmissions can range from a few percent up to 80 or 90% for cirrus clouds. In the presence of clouds measured UVR at the earth's surface can range from practically 0% to 120% of the clear sky value. The enhanced solar UVR (11) is the result of scattering from the sides of cumulus clouds - obviously these levels will only be obtained when the solar disk is not blocked by cloud.

There is still much research to be done in this area. Difficulty arises when there is the need to include cloud cover in computer-generated UVR irradiances. A number of different parameterisations have been used (2). Data for Australia is reasonably well-represented by: $Irrad_{cloud}/Irrad_{clear} = 1 - 0.06C$; where C is the cloud cover in octas.

Cloud droplets which are considerably larger than aerosols are assumed to have scattering cross-sections that will be largely independent of wavelength throughout the UV region and therefore clouds are not expected to have any wavelength dependence transmission factors in the UV.

Four years of daily total erythemal data (in MEDs) is shown in Figure 7 along with the computed clear sky data. The large variation is due mainly to cloud although the enhanced summer values are the result of short-term total ozone reductions.

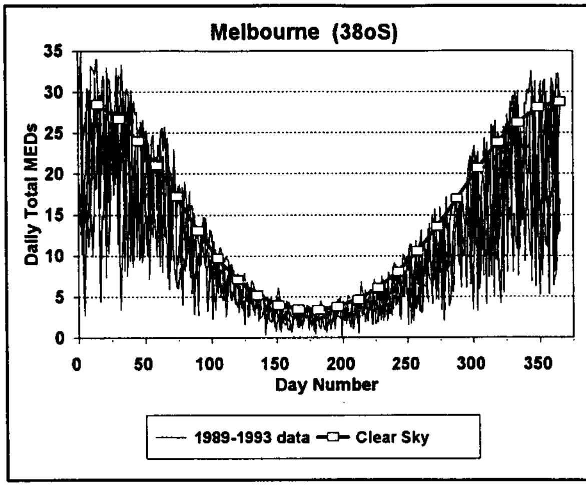


Figure 7. Fours years of erythemal data for Melbourne (37.8°S). Also shown is the computed clear sky data.

Erythemal UVR and SZA

The erythemal UVR is obviously quite dependent on the SZA. With increasing SZA there is a disproportionately greater drop in the UVB than the UVA and because of the greater biological responsivity in the UVB the weighted irradiance will drop at an even greater rate (Figure 8).

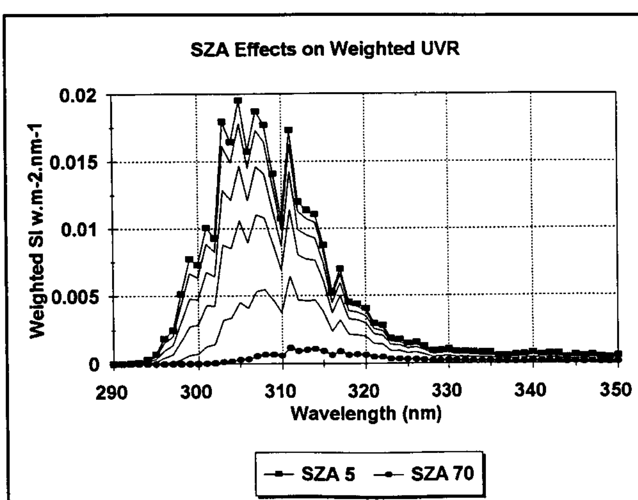


Figure 8. The effect of SZA (5°, 15°, 25°, 35°, 50° and 70°) on the effective spectral irradiance. Computations have been performed for an ozone column of 270 DU. The unweighted spectral irradiances are given in Figure 2.

It can be seen that the peak in the weighted spectral irradiance shifts to longer wavelengths with increasing SZAs.

Table 3 provides the integrated effective irradiances (280-400 nm) for different SZAs. Similar results are also provided for total ozone columns of 300 and 330 DU. The numbers in parentheses give the time (minutes) to reach 1 MED at that constant irradiance. Values range from 10.9 to 190 minutes or 5.50 to 0.3 MEDs/hour.

Table 3
Effect of SZA on the integrated effective irradiance ($W.m^{-2}.nm^{-1}$) for different ozone column amounts. The number in parentheses is the time in minutes to achieve 1 MED.

SZA	270 DU	300 DU	330 DU
5	.307 (10.9)	.269 (12.4)	.239 (13.9)
15	.283 (11.8)	.249 (13.4)	.221 (15.1)
25	.240 (13.7)	.211 (15.8)	.188 (17.7)
35	.185 (18.0)	.163 (20.5)	.145 (23.0)
50	.100 (33.4)	.088 (37.8)	.079 (42.2)
70	.022 (154)	.019 (171)	.018 (187)

Trends in ozone and calculated trend in erythemal UVR

The averaged trend in ozone and the corresponding trend in erythemal UVR is shown in Figure 9 for the period 1979-89 (2).

The asymmetrical nature of the plot is due to the large springtime losses in Antarctica. Unfortunately the erythemal data which has been computed for clear skies has not been verified at this point in time because of the absence of accurate measurement over a sufficient period of time.

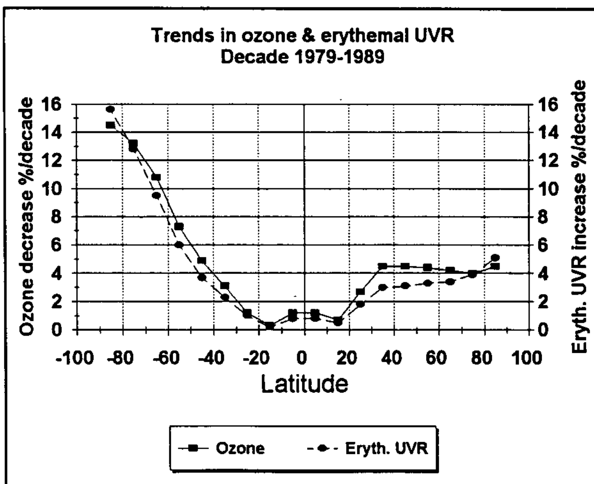


Figure 9. Trend in ozone (zonally averaged) for the decade 1979-89. The computed change in erythemal UVR is also given (2).

Educational campaigns

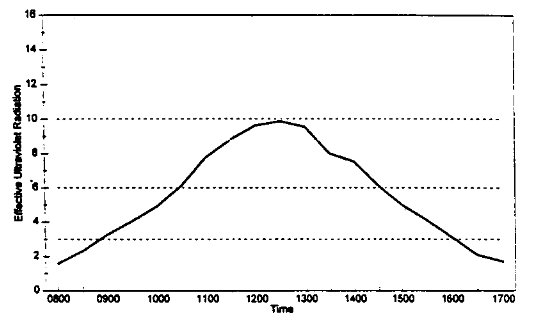
Public and professional education about skin cancer commenced in Australia in about 1960 with programmes in both Queensland and Victoria (12). Since 1981 the Anti-Cancer Council of Victoria has run a "Slip!, Slop!, Slap!" and later "Sunsmart" national campaigns (13). The two aspects to skin cancer control - prevention and early detection - are both embraced by what is now a national program coordinated by the Australian Cancer Society.

The Australian Radiation Laboratory, using data from its national measurement network (14), provides to the media a daily chart of UVB for the capital cities in each state. These are broadcast in the weather section on the nightly television news report. This 12-15 second time slot provides a unique opportunity to reach a large audience and to help educate the public about UVR and the link or otherwise to ozone, cloud cover and daily temperature. This has generated considerable public interest. Figure 10 shows a typical report that is provided to the media at 1700 hours, local time. The template the media uses is colour graded with red and orange representing the highest UV categories.

Figure 10. Typical daily UVR chart provided to the media.

Solar Ultraviolet Radiation Report

Sydney **01/11/1995**



UV-Index

10.1

Recorded at 12:30

Value	Exposure Category
Less than 3	Moderate
3 - 6	High
6 - 10	Very High
Greater than 10	Extreme

Global Solar UV-Index

The index, a joint recommendation of WHO, WMO, UNEP, ICNIRP and IARC (15) is a measure of the solar UV levels relevant to health effects and is useful for warning people about the degree of hazard that existed or could exist on a particular day. The index is calculated by multiplying the daily maximum CIE-weighted UVR, averaged over 30 minutes, by 40. For the first time there will be a global system in place which will make comparisons straightforward and will also assist tourists. Figure 10 also provides the index for the day and this allows the public to compare with the previous day's prediction.

Many schools and community groups are taking a greater interest in minimising UVR exposure and a variety of initiatives have emerged from the enforced wearing of hats in school grounds, modification of the hours that schoolchildren spend outdoors to the planting of more shade trees in open areas. The provision of shade structures in homes, school grounds and in public areas including parks is strongly advocated as a sensible radiation protection strategy. Appropriate materials are available (16,17) although care should be taken in design as users can often still be exposed to scattered solar UVR.

Evaluation of programs

Evaluation of a prevention program measures initially a change in knowledge and attitudes, then a change in behaviour and eventually a change in the incidence and mortality rates of skin cancer (13).

A survey of sunscreen use conducted on Brisbane beaches (18) found about 70% of females and males applied sunscreen. Half of the sunscreens provided the maximum protection (SPF 15+) and almost 90% used a waterproof formulation. However the sunscreen was not applied over the entire body with over half neglecting ears and lower limbs.

Following the introduction of the Sunsmart programme, Hill (19,20) conducted surveys in three summers in the period 1988-1990 to determine trends in exposure to sunlight by monitoring the prevalence of sunburn and sun-related attitudes and behaviours in 4,400 adults. In 1988 up to 18% of some groups reported sunburn in a given weekend. Over the three years the average proportion sunburnt dropped from 11% to 7%. They also found that substantial attitudinal changes also occurred with hat wearing and sunscreen use increased to 29% and 21% respectively. There was no clear trend in the proportion of the body covered by clothing - the mean proportion of body surface area covered being 70%. However, there was significant evidence that beliefs were more realistic and conducive to sun-protective measures.

With regard to skin cancers it is still too early to fully evaluate the effectiveness of the educational campaigns but there are promising indications. It has been reported that excised cutaneous malignant melanomas are becoming thinner which indicates that they are being found earlier (in more than 90 per cent of cases there is no clinical evidence of secondary spread of the cancer) which in turn results in a higher 10 year survival rate (21). In Australia it has been found that melanoma mortality has peaked with figures showing a small but significant fall in rates for women and a plateau in the male death rate. For 1990-91 the age-standardised mortality rates in Australia were 4.9 and 2.5 per 100,000 for males and females respectively (22). It is expected that a consistent fall will be found over the next two years (23).

Conclusions

Much of the world's population reside in locations where it is easy to obtain large doses of solar UVB for at least part of the year. The individual's genetic susceptibility and personal behaviour will determine whether or not exposure will ultimately result in adverse health effects. Continuing atmospheric ozone depletion places even more pressure on the individual to adopt sensible outdoor behaviour.

Educational programs aimed at both the workforce and the public have succeeded in creating an awareness of the dangers of overexposure to ultraviolet radiation. The global solar UV-index is a useful addition to this campaign. The fact that changes in knowledge and attitudes have been accompanied by behaviour changes indicate that educational programmes are having an effect in some countries. Consumers have the products available which will provide good personal protection and the information to enable a proper choice. The adoption of sensible behaviour and personal protection can help to achieve :

- avoidance of sunburn which is accepted to be a major risk factor for melanoma and
- a reduction of an individual's accumulated UVR dose during work and leisure hours which has a role in non-melanoma skin cancer.

References

1. Björn, L.O., *Radiation Measurement in Photbiology*, Academic Press, London, 1989.
2. Madronich, S., *Environmental UV photobiology*, Plenum Press, New York, 1993.
3. WMO, *Scientific assessment of ozone depletion:1991*, WMO Report #25, Switzerland, 1991.
4. CIE Research Note, *CIE J.* 6, 17 (1978).
5. Diffey, B.L., *Phys. Med. Biol.* 37, 2267-2279 (1992).
6. Gies H.P., et al. *SPIE* 2282, 274-284 (19940.
7. Diffey, B.L., *Phys. Med. Biol.* 36, 299-328 (1991).
8. Frederick, J.E., et al., *Photochem. Photobiol.* 54, 781-788 (1991).
9. Jokela, K., et al., *Photochem. Photobiol.* 58, 559-566 (1993).
10 Seckmeyer, G., et al., *Geophys. Res. Letts.* 22, 1889-1892 (1995).
11. Mims, F.M. and Frederick, J.E., *Nature* 371, 291 (1994).
12. Smith, T., *Brit. Med. Journal* 1, 253-254 (1979).
13. Marks, R., *Australas. J. Dermatol.* 31, 1 (1990).
14. Roy, C.R., et al. *J. Photochem. Photobiol. B:Biology* 31, 21-27 (1995).
15. ICNIRP , Global solar UV-index, (in press,1996).
16. Wong, C.F., *Photodermatol. Photoimmunol. Photomed.* 10, 221-224(1994) .
17. Toomey,S.J,et al., *Radiation Protection in Australia* 13, 50-54 (1995).
18. Pincus, M.W., et al., *Australas. J. Dermatol.* 32, 21 (1991) .
19. Hill, D., et al., *Preventive Medicine* 21, 654-669 (1992).
20. Hill, D., et al., *European J. Cancer Prevention* 2, 447-456 (1993) .
21. Marks, R., *Aust. J. Public Health* 18, 127-128 (1994) .
22. Giles, G.G., et al., *Cancer Forum* 18, 12-23 (1994) .
23. Gray, N. Anti-Cancer Council of Victoria, *Media Release* (1995).