Weather and Climate (1992) 12: 83-88

ERYTHEMAL AND CARCINOGENIC ULTRAVIOLET RADIATION AT THREE NEW ZEALAND CITIES

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ABSTRACT

A network of solar carcinogenic/erythemal ultraviolet radiation monitors has been established by the Department of Health — National Radiation Laboratory and the DSIR at a number of centres of population in New Zealand. Daily totals of this biologically harmful, ultraviolet radiation for 1989 and 1990 are reported from the Wellington and Christchurch radiometers and for 1990 from the Auckland radiometer.

The effects of time of year, latitude and cloud cover are apparent in the data and are discussed. However, the monitoring programme has not been running sufficiently long to discern any long-term changes in levels of solar ultraviolet radiation which would result from changes in the stratospheric ozone layer.

INTRODUCTION

Erythema and non-melanoma skin cancers are caused by ultraviolet radiation (Urbach, 1987). The sensitivity of skin with respect to erythema and skin cancer depends on the wavelength of the UV radiation, and the relative efficacies of UV wavelengths in producing a response in skin are expressed as *action spectra*. The action spectra $S(\lambda)$, for erythema (McKinlay and Diffey, 1987) and non-melanoma skin cancers (Sterenborg, 1987) are shown in Fig. 1a.

Stratospheric ozone absorbs much of the harmful UV radiation from the sun. However, a small amount of this radiation reaches the earth's surface at wavelengths longer than about 295 nm. A typical noon, mid-summer solar spectrum, solar zenith angle of 25°, is shown in Fig. 1b. The short-wavelength edge of the solar spectrum is determined by the pathlength of sunlight through the ozone layer and therefore depends on the solar angle: e.g. small solar zenith angles correspond to short ozone pathlengths which allows the transmission of shorter wavelength UV radiation through the atmosphere.

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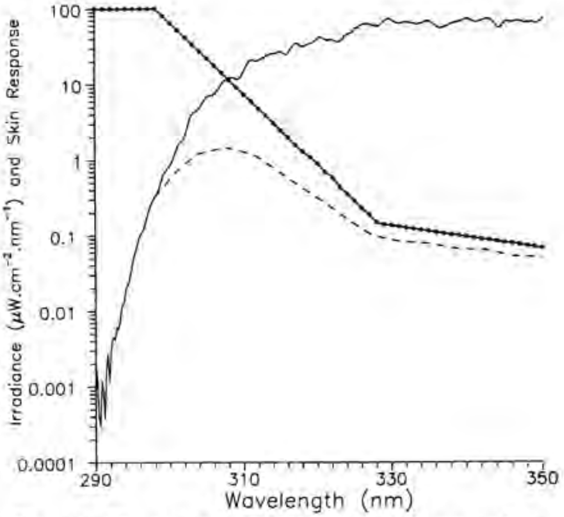

Fig. 1(a): The action spectra for skin erythema and non-melanoma carcinogenesis. ●-●-●-● (b): Solar spectrum recorded at 1220 NZST, 14 January 1990 at latitude 45°S; solar zenith angle 25° ________ (c): Spectrum of erythemally effective irradiance I (λ). S(λ) -----.

Because skin is not equally sensitive to all wavelengths of UV radiation, it is useful to introduce the concept of *effective irradiance* in the measurement of solar erythemal UV radiation (Robertson, 1979; Diffey 1987). The skin effective irradiance at wavelength λ , is the intensity of solar radiation, I(λ), weighted (multiplied) by the sensitivity of skin, S(λ). Such irradiances can be thought of as equivalent to that hypothetical irradiance of monochromatic radiation at wavelength λ which would require the same exposure time as sunlight to result in erythema. A spectrum of erythemally effective irradiance at a solar zenith angle of 25° is shown in Fig. 1c. It is found that the most effective wavelengths of solar UV radiation for producing erythema and skin cancer at all sun angles encountered in New Zealand (summer and winter) lie in a narrow range from 308-311 nm.

Measurement of solar, erythemal radiation is a technically demanding task. This is because small deviations in the spectral response of the detector from the erythemal spectral response of skin, i.e. the action spectrum, can lead to large systematic errors in the measurements. A UV radiometer is now available which provides a reasonably close match to the erythemal/carcinogenic action spectrum of skin. A number of these radiometers are in operation in Australia (Roy et al., 1989) and radiometers of the same design have been installed at centres of population throughout New Zealand. Radiometers are now operated in Auckland, Wellington, Christchurch and Dunedin by the DSIR and the Department of Health. There are two further radiometers in Hamilton and Nelson. The erythemal irradiance data collected to date from the first three radiometers to be commissioned, i.e. Auckland, Wellington and Christchurch, are presented in this report.

METHOD

Actinic UV radiometers type SED240/ACTS270/W were purchased from International Light Inc, Newburyport, USA. These radiometers consist of a diffuser, an interference filter, and a solar-blind phototube. The output of the phototube is amplified by a high-gain preamplifier. The absolute responsivities of the radiometers were obtained by comparison with a NIST(USA),F167 standard lamp. The relative spectral responsivities were determined with a spectroradiometer and reference to a Rhodamine B quantum counter. The angular responses of the radiometers with respect to a point source at a distance of 1 m from the radiometers were also determined. The radi-

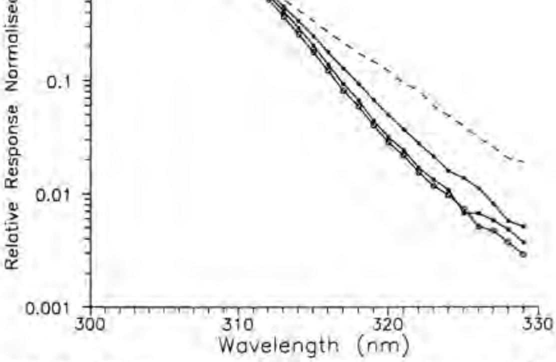

Fig. 2: The erythemal action spectrum - - - - - ; the response spectra of the Auckland radiometer 0 — 0 ; the Wellington radiometer ●-●-●-●; and the Christchurch radiometer ■ — ■ . All spectra have been normalised at 310 nm.

ometers are recalibrated each year. The spectral responsivities of the Auckland, Wellington and Christchurch radiometers are shown in Fig. 2 and for comparison, the erythemal action spectrum is also shown in Fig. 2.

There are small differences in the spectral responsivities of the radiometers and this will result in differences in the responses (measurements) made by the instruments. The magnitude of this inter-instrument variation was established by calculating the expected radiometer responses to various solar spectra. The expected, or calculated, radiometer response to solar radiation with a spectrum $I(\lambda)$ effective at a wavelength λ_e is

$$c \cdot \sum_{\lambda=290}^{350} I(\lambda) \cdot R(\lambda) \cdot \Delta\lambda$$

where $R(\lambda)$ is the absolute spectral responsivity of the radiometer and c is the constant of normalisation at λ_e nm. The radiometer response depends on the wavelength chosen for normalisation and the normalising wavelength which results in the least variation between the calculated radiometer responses to different solar spectra (different sun angles) was determined. The solar spectra used for these calculations were measured at a number of different solar angles at DSIR-Physical Sciences, Lauder, Central Otago (45°S), using a Jobin Yvon DH10 double monochromator as part of a programme to establish a climatology of UV spectral irradiance. Details of the spectroradiometer are given elsewhere (Bittar and McKenzie, 1990).

The International Light radiometers are mounted with a front window horizontal and positioned where they receive unobstructed, direct and diffuse solar radiation from the whole sky to within about 20° of the horizon. The UV irradiance as measured by the detection system is sampled 80 times every minute and this data is averaged over a 10-minute period. Each 10-minute average value of irradiance measured from 0600 to 1800 NZST is logged and archived.

The UV irradiances presented in this report are erythemally effective irradiances at 310 nm. 300 nm and 297 nm have been used previously as reference or normalising wavelength for reporting data of this kind. However, 310 nm was chosen as the reference wavelength in this work covered by the most effective wavelengths of solar radiation for effective wavelengths of solar radiation for producing erythema and non-melanoma skin cancer throughout the year in New Zealand. Also when irradiances are expressed in terms of a 310 nm reference or normalising wavelength, it is found that the variation between the calculated radiometer responses to different solar spectra is small (< 10%).

RESULTS AND DISCUSSION

Variation in Irradiance Measurement

The variation between the irradiance measurements made by the three radiometers were

TABLE 1: CALCULATED RADIOMETER RESPONSE FOR TYPICAL NEW ZEALAND MIDDAY SOLAR ZENITH ANGLES

Solar Zenith Angle	Normalising Wavelength λ_e (nm)	Calculated Radiometer Response (μW.cm^{-2})		
		Christchurch	Wellington	Auckland
25° (Summer)	300	50.06	60.74	48.82
	305	82.64	98.33	88.15
	310	219.0	218.9	221.8
	315	1220.9	880.27	1079.4
68° (Winter)	300	3.87	5.40	3.93
	305	6.39	8.75	7.10
	310	17.90	19.47	16.94
	315	94.42	78.31	86.98

analysed using the procedure described above. The expected responses of the three radiometers to typical New Zealand midday summer solar radiation (zenith angle of 25°) and winter solar radiation (zenith angle of 68°) normalised at different wavelengths, λ_e were calculated. The results of these calculations are presented in Table 1. Use of 310 nm as the normalising wavelength was found to result in the smallest inter-instrument variation in calculated reponses to different solar spectra for the three radiometers.

Erythemally Effective Irradiances in New Zealand

Daily totals of the 10 min average, erythemally effective irradiances at 310 nm are shown in Figs. 3-7. The doses of erythemally effective radiation are given in units of J.m^{-2} at 310 nm. Although intrinsically less precise, another unit known as the Minimum Erythemal Dose (MED) is relevant to the effects of UV radiation on human skin. The MED is the dose of UV radiation which produces just perceptible reddening of the skin in untanned subjects. The MED depends on the genetically determined sensitivity of an individual to UV radiation. A range of MEDs have been reported in the literature. For example, the mean 24h. MED determined for fair-skinned British subjects is ~2300 J.m^{-2} at 310 nm (Diffey et al., 1984) while for a sample of fair-skinned American subjects, the 24h. MED at 310 nm was ~3900J.m^{-2} (Parris et al., 1982).

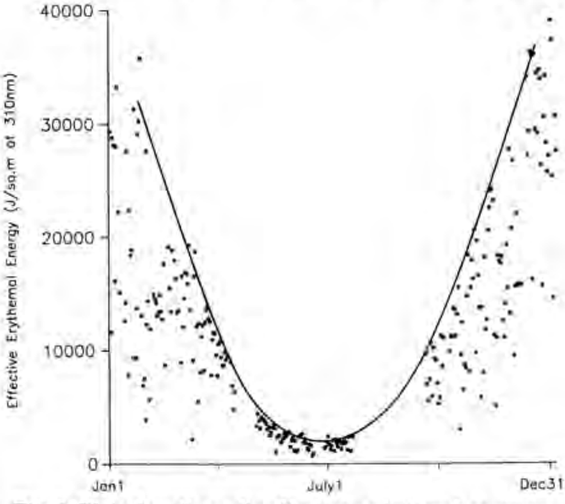

Fig. 3: Plot of erythemally effective radiation dose versus day of year for Auckland, 1990.

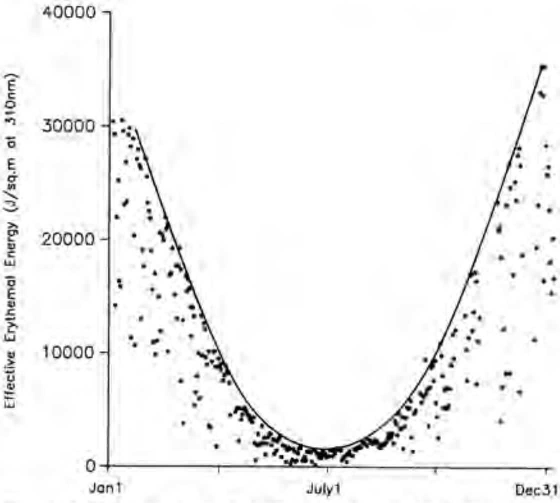

Fig. 4: Plot of erythemally effective radiation dose versus day of year for Wellington, 1989.

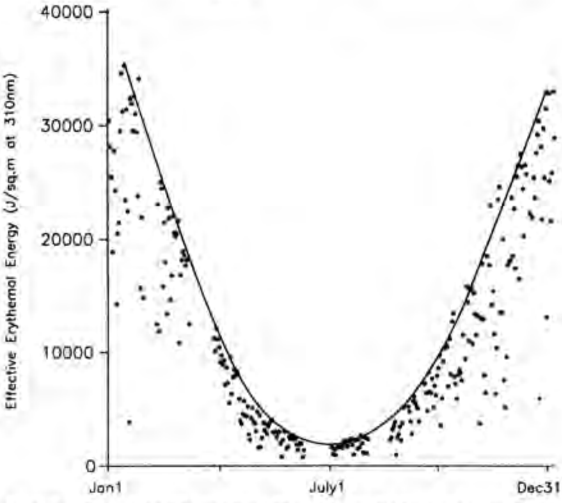

Fig. 5: Plot of erythemally effective radiation dose versus day of year for Wellington, 1990.

A feature of the daily total irradiance data shown in Figs. 3-7 is the considerably lower levels of radiant energy experienced during the winter months compared with summer. This is a consequence of erythemal UV radiation being absorbed by the stratospheric ozone layer which exists mainly at 15-25 km above the earth's surface (Frederick, 1990) and the transmitted intensity of this radiation de-

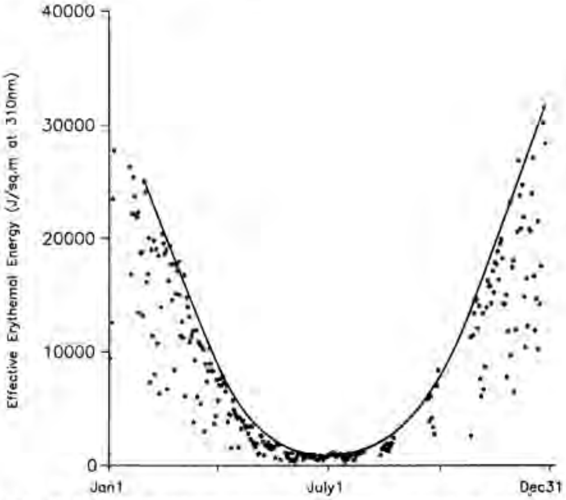

Fig. 6: Plot of erythemally effective radiation dose versus day of year for Christchurch, 1989.

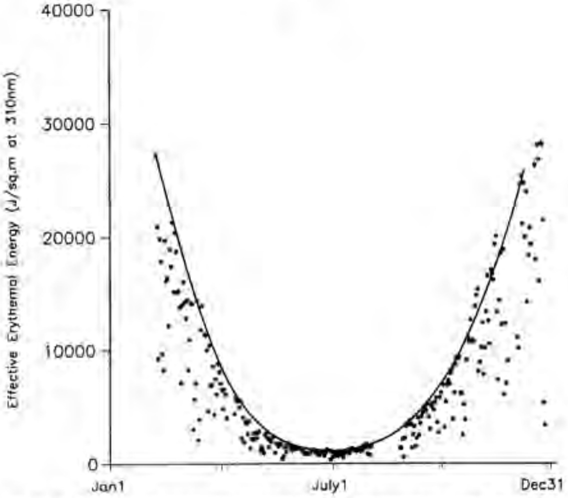

Fig. 7: Plot of erythemally effective radiation dose versus day of year for Christchurch, 1990.

creasing exponentially as its pathlength through the ozone layer increases. Since this pathlength is a function of sun angle, the intensity of solar erythemal UV reaching the earth's surface is very sensitive to sun angle. Because solar zenith angles are large during winter, the intensity of erythemal radiation reaching the ground is low at this time of year. Erythemal radiation is far more affected by sun-angle than are UVA (i.e., UV longer than 320 nm) and visible radiations, which are not absorbed by ozone. The sensitivity of erythemal UV radiation to sun angle is also apparent as a large diurnal variation in irradiance. A typical plot of solar erthyemal UV irradiance versus time of day on a clear-sky day during mid summer is shown in Fig. 8. It is also apparent from Figs. 3-7 that there are substantial day-to-day differences in erythemal UV radiant energy resulting from daily variations in cloud cover and stratospheric ozone levels. Although the effect of clouds on solar UV radiation at the earth's surface is not well defined at present, a number of qualitative observations can be made. Clouds located directly between the observer and the sun will result in an attenuation of the radiation, with the extent of this attenuation dependent on cloud thickness and height. Clouds elsewhere in the sky will generally attenuate the diffuse component of solar radiation. However, on occasions, clouds which are not directly between the observer and the sun can increase the total observed UV radiance. Presumably these clouds are acting as secondary sources of solar radiation (scatterers).

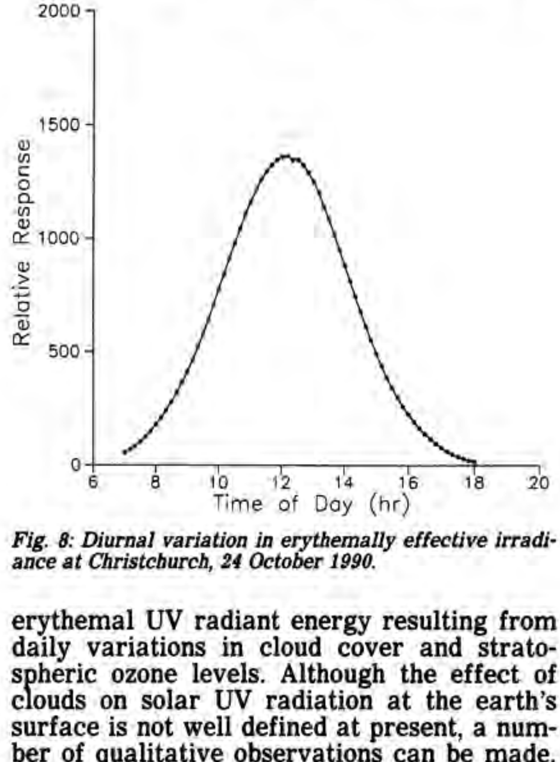

Fig. 8: Diurnal variation in erythemally effective irradiance at Christchurch, 24 October 1990.

Given the unpredictable and non-quantifiable effects of clouds on solar erythemal radiation, comparison and analysis of the data presented here is confined to clear-sky conditions. Inspection of the graphs of daily totals of erythemally effective irradiances reveals

reasonably well defined upper envelopes for UV radiant energy. These envelopes are shown by the curves in Figs. 3-8 and correspond to the daily total UV energies in the absence of cloud and for temporally averaged ozone levels. Comparison of these curves for Auckland, Wellington and Christchurch shows the expected latitudinal trends, i.e. higher UV radiant energies, at the same time of the year, at lower latitudes than at higher latitudes. As yet, there is not a sufficiently long and reliable data set to establish statistically significant long-term trends in levels of solar erythemal radiation in New Zealand. Although a good deal of speculation surrounds the possibility of increases in solar erythemal radiation as a result of global ozone depletion (Frederick 1990; Scotto et al., 1988; Blumthaler and Ambach, 1990), the extent to which such changes in levels of stratospheric ozone affect erythemal UV irradiances is variable. This is because the ozone pathlength is such an important factor in determining atmospheric UV transmissions at these wavelengths, should there be a reduction of stratospheric ozone during winter, it would only have a small effect on erythemal UV levels because of the low sun angles, (i.e. long ozone pathlength) encountered at this time of the year. Only after long term data sets of erythemal UV irradiance have been obtained, can unequivocal conclusions be reached regarding changes in harmful solar UV radiation levels in New Zealand.

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