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# Analysis of Three Years' Measurements of Erythemal Ultraviolet Radiation at Invercargill, New Zealand

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NEW ZEALAND METEOROLOGICAL SERVICE

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## Summary

An analysis has been made of thirty-seven months of half-hourly integrals of sunburning ultraviolet (UV) radiation measured at Invercargill, New Zealand (46.4°S) with a Robertson-Berger (RB) sunburn UV meter.

The data are marked by significant diurnal, seasonal and cloudiness-dependent variations. Two-thirds of the yearly total was received in the four summer months of November to February, and the average mid-winter noon value was exceeded in mid-summer from about 0730 to 1800 New Zealand Standard Time (NZST). Cloudiness caused some days' totals to drop to a sixth of the expected clear-sky values, and resulted in monthly mean daily values of typically 60 percent of the expected monthly mean clear sky values. RB meters are known to suffer from systematic error as a function of zenith angle, due to mainly the imperfect match of their sensitivity to the erythemal spectrum. Corrections are possible for clear sky data only. Corrected data for the few clear days available showed an increase in the seasonal contrast but no other great differences.

Comparisons with data from Minneapolis and Bismarck, which lie at about 46°N in the United States, showed similar behaviour for all three sites. Invercargill records summer maximum daily totals greater by about 10 percent on occasion, but as a result of greater average cloudiness, it generally shows noticeably lower average monthly values, even in summer (comparing like seasons).

Overall, the Invercargill data are in accord with theoretical expectations and with measurements made elsewhere, and they provide no support for the popular public view that New Zealand experiences excessive solar UV radiation exposure.

# 1 INTRODUCTION

High rates of incidence of skin cancer and premature materials failure in New Zealand (Basher, 1981) have led to popular speculation that New Zealand's ultraviolet (UV) climate is relatively harsh. The characteristics of both the Earth's orbit and the atmosphere's haze do provide some physical basis for expecting a little more UV radiation at New Zealand sites compared to Northern Hemisphere sites. However, the main determinants are latitude and cloudiness, and for sites of similar latitude and cloudiness there is no basis for expecting any great differences.

As part of an effort to better understand New Zealand's UV climate, the New Zealand Meteorological Service established a measurement programme in 1981 at its Invercargill office using a Robertson-Berger (RB) sunburn meter (Robertson, 1969, and Berger, 1976) donated to it by the chemical company CIBA-GEIGY New Zealand Limited. The instrument is also part of a worldwide network of about twenty RB sunburn meters which is co-ordinated by Temple University's Skin and Cancer Hospital in Philadelphia.

The RB sunburn meter has a spectral sensitivity approximately matched to the 'erythemal' spectrum, i.e., to the sensitivity spectrum of human skin 'reddening', or sunburning, as shown in Figure 1. Skin cancer is also thought to be associated with this part of the solar spectrum, which lies between wavelengths of about 290 and 320 nm.

The objectives of this present report are to summarise the available thirty-seven months of sunburn UV data, in terms of means, extremes, and diurnal, seasonal, and interannual variations; to compare these data with those recorded at sites of similar latitude in the Northern Hemisphere; and to help put to rest some of the wilder claims about New Zealand's UV climate.

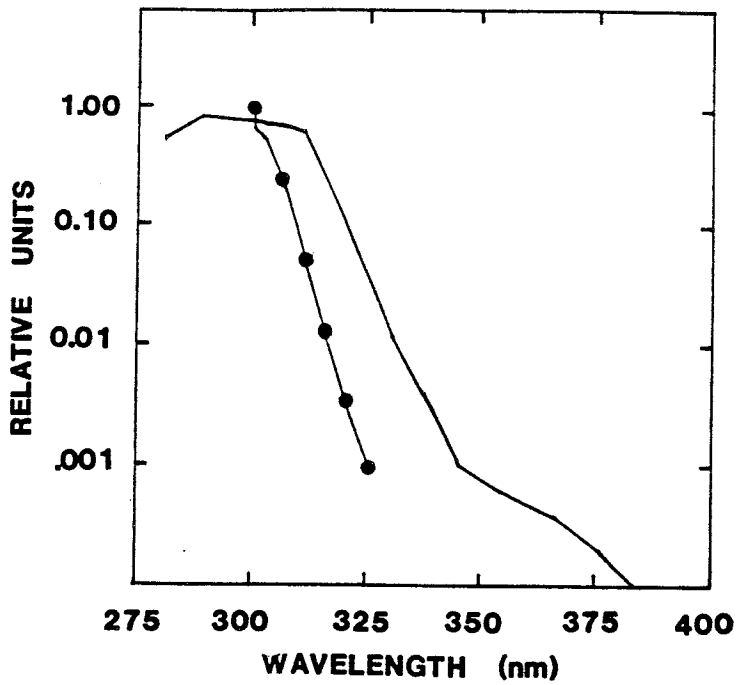


Figure 1. Erythema action spectrum (●—●) and RB sunburn meter spectral response (——). (Data from Barton, 1983).

## 2 DATA

The RB sunburn meter records the total amount of erythemal UV radiation received over 30-minute intervals set to end on the hour or half hour referred to local mean solar time (1247 NZST). For this reason the half-hourly data are referred to the nearest whole or half hour NZST, e.g., to 1230 for the half hour from 1217 to 1247. These half-hourly recordings may range from 0 to 800 "RB counts", depending on the time of day, season, and the prevailing meteorological conditions. By way of reference to these values, Berger (1976) states that a half-hourly count of 440 represents a dose which can cause minimal erythema on an untanned average Caucasian skin. The instrument's output cannot readily be expressed in standard physical units, and is left in terms of the instrument-dependent, but calibrated, RB counts.

The instrument measures the radiation incident on a horizontal surface. To obtain estimates of the radiation incident on other surface orientations, it is necessary to separately consider the effects of the direct beam, the sky radiation, and the radiation reflected from the ground. This report presents data for only the horizontal surface, and does not consider the case of other orientations.

The RB sunburn meter is sited at Invercargill (latitude 46.4°S, longitude 168.35°E, altitude 1 m), which is at the southern end of the South Island. The site is close to the coast and is fully exposed to the prevailing moist, cloudy, and cool winds from the south to west quarters. The instrument was installed on 3 September 1981 and is still operating. Continuous monthly records of data are available from October 1981 onward except for the following periods: November 1983, January 1984 - July 1984. This report analyses the data up to and including July 1985.

Invercargill's southern latitude and cloudy climate mean that it is not representative of the more northern parts of the country. For example, the mean annual solar radiation at Auckland (37°S) is 24 percent higher than Invercargill's mean of 4600 $MJm^{-2}$ , and the sunnier parts of the country receive on average 60 percent of possible sunshine during the summer compared to Invercargill's summer average of 40 percent. Invercargill was chosen as the site partly because Temple University was already sponsoring an instrument at Waikato Hospital in Hamilton (38°S), and partly because Invercargill is a technically well-supported Meteorological Office and is New Zealand's only column-ozone monitoring station. As yet, no data summaries or analyses for the Waikato Hospital station have been sighted by the authors.

The calibration of the sunburn meter was checked in January 1982 and January 1983 by comparison with a reference RB sunburn meter which is circulated by Temple University to test the instruments in the network. These checks implied that the Invercargill sunburn meter was reading 15 percent too high in January 1982, and 9 percent too high in January 1983. The standard error of the calibration technique has been found to be about 5 percent (Berger, personal communication) and so a fixed 10 percent correction (i.e., a factor of 10/11) has been applied to the raw Invercargill data.

Two stations in the American network, Bismarck (latitude 46.8°N, altitude 510 m) and Minneapolis (latitude 44.9°N, altitude 250 m) are at similar latitudes to Invercargill. To enable comparisons to be made, the results for Invercargill will be presented where possible in the same form as that used in the extensive summary of 1974 data from the American network by Scotto et al., 1976. RB sunburn meters are also sited at Melbourne (38.0°S) and Oakland (37.7°N), and some results from these two stations (Berger and Urbach, 1982) will be included to provide another comparison between Southern and Northern Hemisphere sites at a similar latitude.

## 3 ANALYSIS OF DATA - ALL SKY CONDITIONS

The UV measurements at Invercargill are considered in terms of diurnal, daily, and interannual variations. The diurnal variation is studied using monthly average half-hourly RB counts, i.e., the half-hourly RB counts for each particular time of the day are averaged over a month. Similarly, the half-hourly RB counts are summed for each day to give a daily total, and these daily totals are averaged over a month to give monthly average daily RB counts.

It should be noted that the data analysed in this report are generally expressed in units of RB counts. It is known that the RB sunburn meter overestimates the erythemal dose with increasing zenith angle (Berger and Urbach, 1982). Correction factors can be applied to give more accurate estimates of clear sky erythemal radiation, but they cannot be applied to all data. Further discussion of this point is given in Section 4.

Clouds affect the UV irradiance and normally reduce it below the clear sky value. An examination of the underlying variations in cloud-free and zenith angle corrected data was made and is discussed in Section 4.2.

## 3.1 Diurnal variation and intensity levels

### 3.1.1 Diurnal variation

Figure 2 shows the average diurnal variation within each of the last six months of 1982. The data are relatively sharply peaked around the middle of the day, which is due to the strong atmospheric absorption for the low solar elevations of the mornings and afternoons.

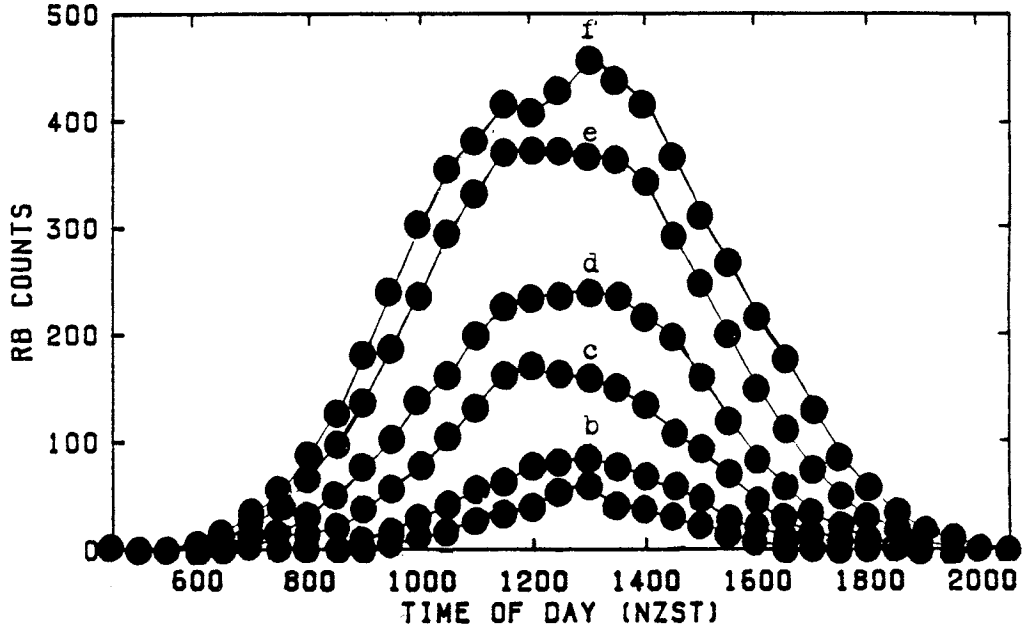


Figure 2. Diurnal variation in average RB counts per half hour for July 1982 to December 1982.

| | |
|---|---|
| (a) July | (b) August |
| (c) September | (d) October |
| (e) November | (f) December |

The data have moderate diurnal symmetry, but some asymmetry is evident in the September and December data, due to diurnal variation in cloudiness. The September data are skewed over the mid-day period, which is consistent with the solar radiation (300-3000 nm) charts for September 1982 tending to have large drops in values between 1200 am and 1430 NZST (Figure 3), apparently due to increased cloudiness. Similarly, the reduction in

December's average RB count between 1130 and 1300 NZST shown in Figure 2 corresponds to large drops in solar radiation during this period.

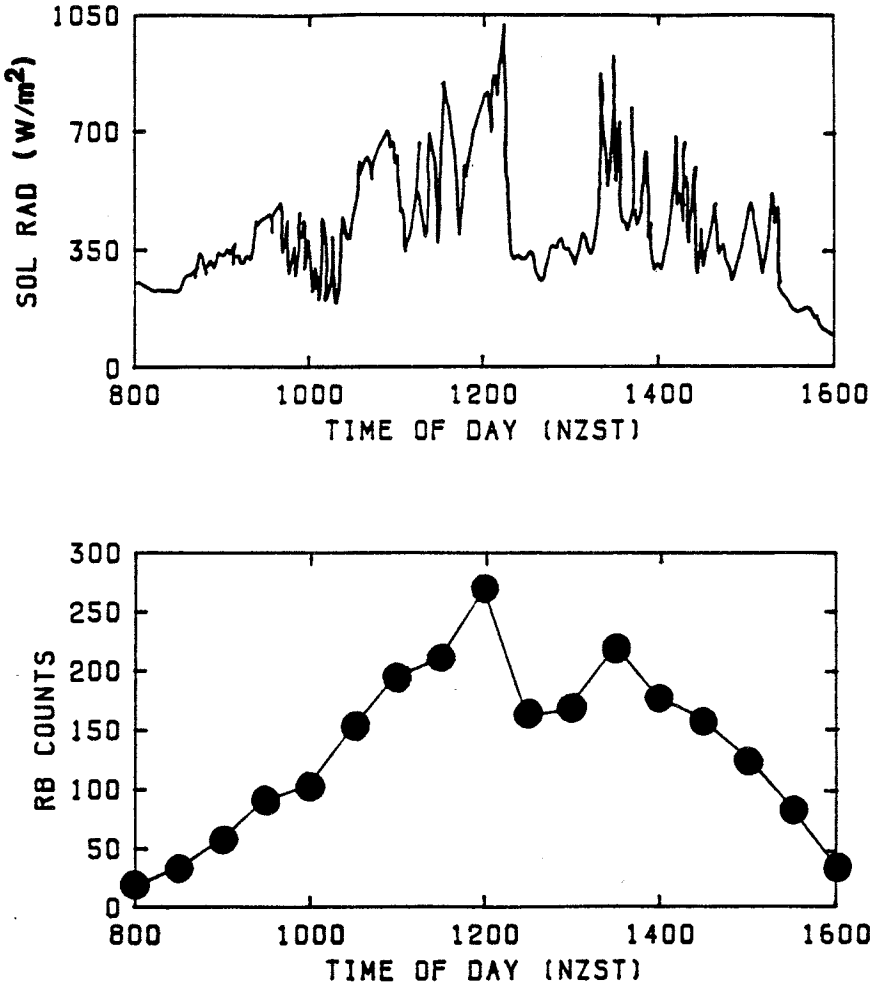


Figure 3. Comparison of RB counts per half hour and continuous solar radiation chart for 24 September 1982, showing the effect of noon cloudiness on both.

As suggested in the preceding paragraph, there can be large day to day differences in measured RB counts arising from changes in cloudiness. These large variations, indicated by a large difference between the maximum and minimum half-hourly RB counts, are shown in Figure 4. All months show this marked variation.

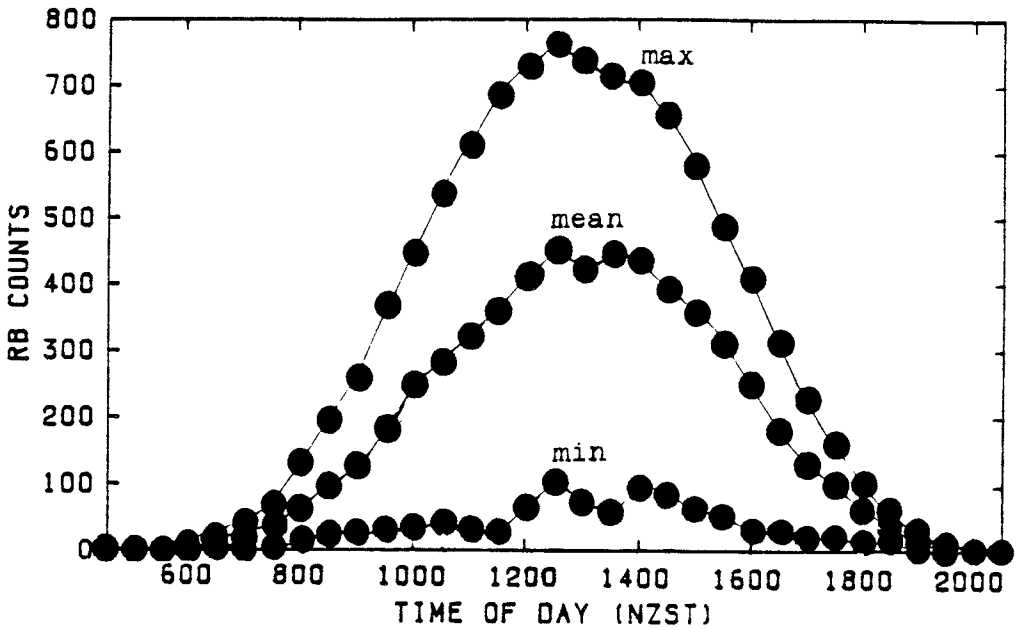


Figure 4. The maximum, mean, and minimum RB counts per half hour for January 1982. This illustrates the large variations due to cloudiness.

A certain degree of variation in RB counts for each half hour within a month is due to the seasonal march of the solar declination, and hence of the solar zenith angle. This variation will be greatest in the equinoctial period. Variations due to changes in the amount of atmospheric ozone will also be present.

Returning to Figure 2, the seasonal variation in the diurnal pattern is clearly shown by the substantial difference in the average RB counts recorded in the summer months and in the winter months. The average RB count received at mid-day in July is about 1/10th that received in January. The average mid-winter peak half-hourly RB count (at mid-day) is exceeded in the summer months from 0730 to 1800 NZST. The instrument records non-zero RB counts for about fifteen hours each day in summer, and about eight hours each day in winter. The months between mid-summer and mid-winter show a progressive decrease in RB counts, with the most dramatic changes occurring near the equinoxes.

### 3.1.2 Intensity levels

The data were examined to determine the fraction of days that particular intensity levels were exceeded for given periods. The results are shown in Table 1. As was noted earlier, 440 RB counts can cause perceptible erythema on untanned Caucasian skin. Using this value, as a convenient point of reference, one can see that the rate of 440 RB counts per half hour was not exceeded for about 74 percent of the days (and therefore was exceeded for about 26 percent of the days).

Table 1. Percentage of days in year during which intensity value was exceeded for specified number of hours.

October 1981 to September 1982:

| Half-Hourly Intensity | Never Exceeded | Exceeded 0.5-3 hr | Exceeded 3-6 hours | Exceeded 6+ hours |
|---|---|---|---|---|
| 100 | 31.0 | 11.2 | 18.9 | 38.9 |
| 200 | 47.7 | 12.9 | 19.1 | 20.3 |
| 400 | 69.0 | 15.7 | 14.5 | 0.8 |
| 440 | 72.6 | 14.8 | 12.4 | 0.3 |
| 600 | 87.7 | 9.9 | 2.5 | 0.0 |

October 1982 to September 1983:

| Half-Hourly Intensity | Never Exceeded | Exceeded 0.5-3 hr | Exceeded 3-6 hours | Exceeded 6+ hours |
|---|---|---|---|---|
| 100 | 31.5 | 11.6 | 21.6 | 35.3 |
| 200 | 57.8 | 12.3 | 19.4 | 16.5 |
| 400 | 70.7 | 18.6 | 6.3 | 0.3 |
| 440 | 74.2 | 17.0 | 8.8 | 0.0 |
| 600 | 93.2 | 6.3 | 0.5 | 0.0 |

On about 9 to 12 percent of the days, this rate of 440 RB counts per half hour was exceeded for a total of more than three hours and less than six hours. These are the days when prolonged exposure can readily lead to sunburn. On the other hand, Table 1 shows that on 31 percent of the days, the count rate never exceeded 100 RB counts per half hour.

Of course it is in the summer that the long periods of high count rates occur. This is well illustrated by the frequency plot in Figure 5, which shows that the count rate of 440 counts per half hour is exceeded only during the months of October to March.

The maximum half hourly totals at Invercargill typically are between 700 and 800 RB counts and occur any time between late November and early February. On occasion, the clear sky maxima may be exceeded if the cloud present is such as to enhance the diffuse radiation but not obscure the direct solar radiation.

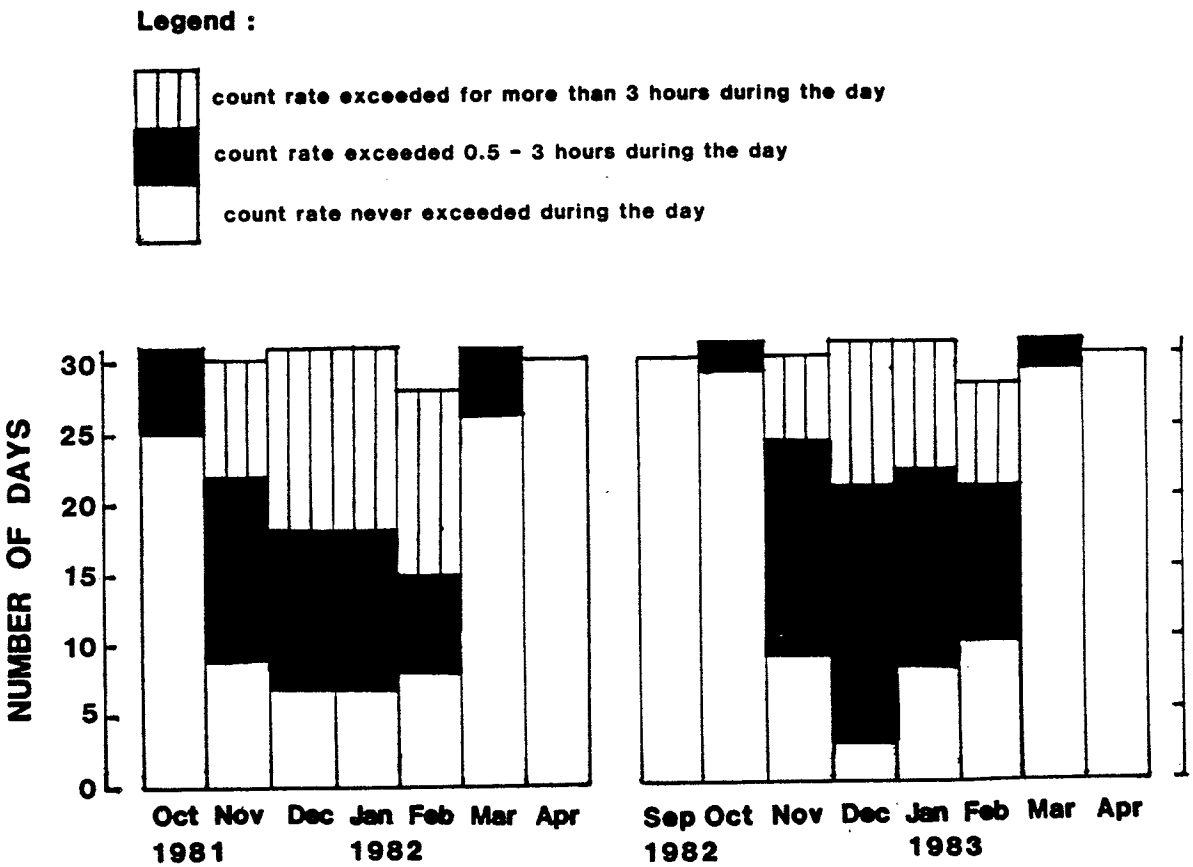


Figure 5. Number of days in each month when the count rate of 440 RB counts per half hour is exceeded.

## 3.2 Daily UV counts

### 3.2.1 Seasonal variation and extremes

The daily totals for the entire period under consideration are plotted in Figure 6. The variation in daily RB counts is strongly characterised by, firstly, the cyclic seasonal pattern, and secondly, the large day to day scatter due to cloudiness. The envelope of maxima has maximum values of between 9000 and 10,000 RB counts per day in summer, dropping to values of about 400 RB counts per day in winter. On cloudy days the day's total may fall to as low as a sixth of the clear sky value.

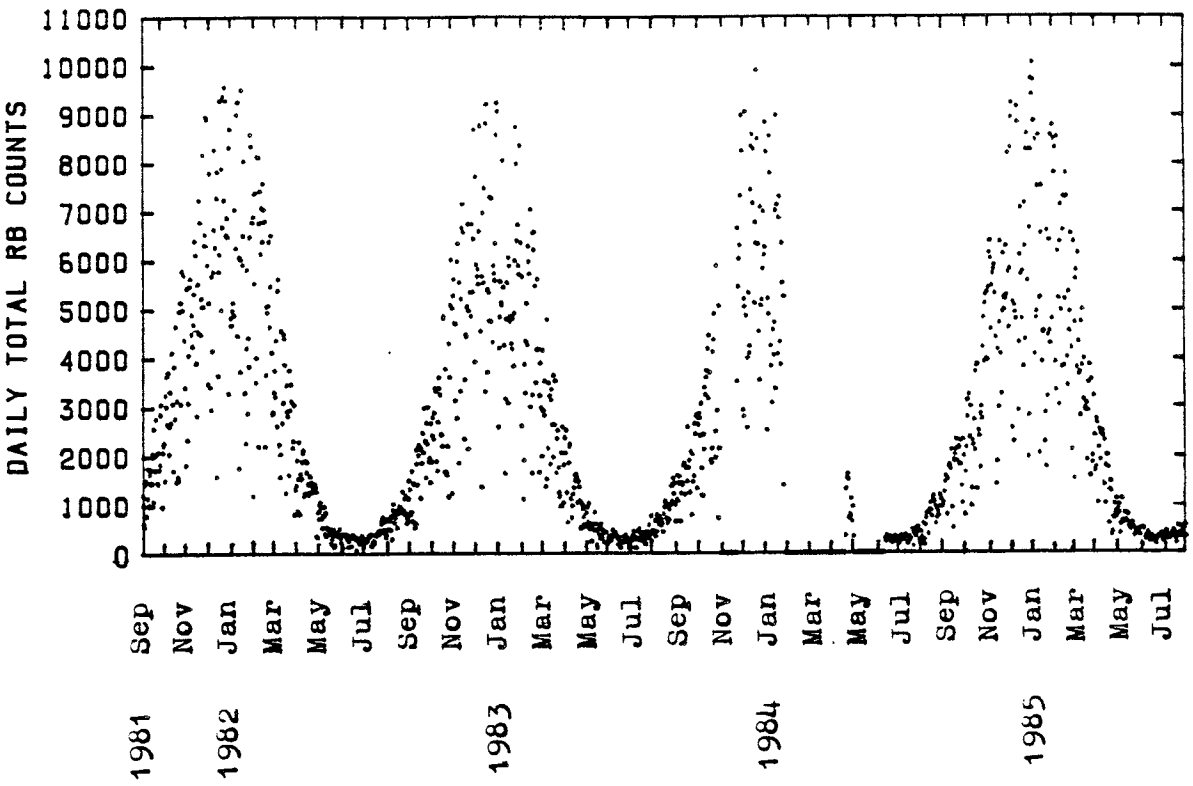


Figure 6. Daily total RB counts for whole period, showing pronounced annual cycle and effect of clouds. The ticks on the horizontal axis refer to the first day of the month.

Table 2 lists the monthly means and other statistics for all the available complete months. The table confirms the points made in the above paragraph in showing the marked daily and seasonal variations. The magnitude of the variation is comparable to that shown in Figure 4 for individual half-hourly counts.

Some of the variation will be due to the change in ozone amount. A one percent change in ozone is expected to give about a 1.7 percent change in erythemal UV radiation and, because of instrument systematic error, about a 1.25 percent change in RB count (DeLuisi and Harris, 1983. See also Section 4). There is a roughly sinusoidal seasonal variation in ozone of about 30 percent range, with the maximum in late winter and early spring, which implies a range of variation in RB counts due to ozone of about 37 percent.

No specific examination of the UV-ozone relationship was made, but the spring data certainly appear lower than the corresponding autumn data. In Table 2 the data of the autumn equinoctial month of March are not matched until the post-equinoctial month of October.

### 3.3 Interannual variation

The data record from Invercargill is relatively short and is broken, so it is not possible to determine good yearly averages, and it is certainly not possible to determine trends, if any, in the record. The annual totals are about one million RB counts, with actual values for various twelve month periods being given in Table 3, along with corresponding solar radiation data (300 nm to 3000 nm).

The interannual variation in RB counts (a 9 percent range) is only partly reflected in the variation in total solar radiation measured at Invercargill over these periods. In particular, the annual total RB count for August 1984 to July 1985 period appears to be inconsistently large, by about 10 percent, when compared to the relatively low solar radiation total for the period. Table 2 shows relatively high RB count totals for all the months of December 1984 to July 1985. This may indicate an instrument

Table 2. Statistics of average daily RB counts by month with mean, standard deviation, coefficient of variation (standard deviation / mean) in percent, and maximum.

1981:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mean | | | | | | | | | | 3292 | 5232 | 6246 |
| s.d. | | | | | | | | | | 1286 | 1717 | 2058 |
| c.v. | | | | | | | | | | 39.1 | 32.8 | 32.9 |
| max | | | | | | | | | | 5781 | 8968 | 9580 |

1982:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mean | 5761 | 5470 | 3065 | 1438 | 540 | 305 | 388 | 778 | 1740 | 2864 | 4804 | 6019 |
| s.d. | 2059 | 1885 | 1155 | 447 | 248 | 90 | 144 | 230 | 660 | 1202 | 1541 | 1780 |
| c.v. | 35.7 | 34.5 | 37.7 | 31.1 | 46.0 | 29.4 | 37.1 | 29.5 | 37.9 | 42.0 | 32.1 | 29.6 |
| max | 9516 | 8144 | 5626 | 2297 | 1060 | 423 | 760 | 1285 | 3009 | 6002 | 7163 | 9209 |

1983:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mean | 5387 | 4627 | 2562 | 1382 | 498 | 294 | 359 | 827 | 1599 | 3036 | | 5980 |
| s.d. | 1793 | 1828 | 984 | 597 | 219 | 102 | 134 | 321 | 549 | 1161 | | 1932 |
| c.v. | 33.3 | 39.5 | 38.4 | 43.2 | 44.0 | 34.8 | 37.4 | 38.9 | 34.4 | 38.2 | | 32.3 |
| max | 9240 | 8356 | 4789 | 2595 | 1036 | 485 | 777 | 1545 | 2849 | 5891 | | 9908 |

1984:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mean | | | | | | | | 801 | 1678 | 3100 | 5082 | 6086 |
| s.d. | | | | | | | | 286 | 479 | 1133 | 1380 | 2311 |
| c.v. | | | | | | | | 35.7 | 28.6 | 36.5 | 27.2 | 38.0 |
| max | | | | | | | | 1200 | 2337 | 5344 | 8190 | 9721 |

1985:

| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| mean | 5844 | 5060 | 3369 | 1482 | 591 | 324 | 394 | | | | | |
| s.d. | 2337 | 2039 | 1244 | 711 | 220 | 106 | 132 | | | | | |
| c.v. | 40.0 | 40.3 | 36.9 | 48.0 | 37.2 | 32.8 | 33.5 | | | | | |
| max | 10056 | 8525 | 6141 | 2646 | 1166 | 517 | 696 | | | | | |

problem, but this remains unresolved at the time of writing.

The analysis of the frequency of occurrence of different RB count intensities (Section 3.1.2, Table 1) showed a similar interannual variation.

Table 3. Annual total RB counts and their comparison with measured solar radiation totals for the same periods.

| | RB Counts | | Solar Radiation | |
|---|---|---|---|---|
| Period | annual total | ratio to period Jan82-Dec82 | annual total $MJm^{-2}$ | ratio to period Jan82-Dec82 |
| Oct 1981 - Sep 1982 | 1036780 | 1.03 | 4617 | 1.00 |
| Jan 1982 - Dec 1982 | 1003635 | 1.00 | 4600 | 1.00 |
| Oct 1982 - Sep 1983 | 945922 | 0.94 | 4370 | 0.95 |
| Aug 1984 - Jul 1985 | 1024395 | 1.02 | 4352 | 0.95 |

## 3.4 Comparison with overseas data

As was noted previously, the main factors which determine the amount of solar radiation received are latitude and cloudiness. Invercargill is at a similar latitude to Bismarck and Minneapolis, but it is rather cloudier. The solar radiation data presented in Table 4 (WMO, 1983) indicate that Invercargill receives about 10 to 15 percent less solar radiation (300 - 3000 nm) than Bismarck. The sunshine duration data in Table 5 (U.S. National Climatic Center, 1976--1979) show an even greater difference, with Invercargill receiving about 40 percent fewer hours of sunshine than the two American sites.

Available cloud cover data do not reflect the large differences seen in the sunshine data. The average cloud cover for both Bismarck and

Minneapolis in 1974 was about 6.3 tenths of sky cover, while at Invercargill in 1982 it was 6.7 tenths (5.4 eighths). These years may not be representative, but at face value the data imply that the cloud types and their radiation transmission properties are very different, which is consistent with the fact that Invercargill has a moist maritime climate whereas Bismarck and Minneapolis have drier continental climates.

Table 4. Comparison of Invercargill's full-spectrum solar radiation by month with Bismarck's full-spectrum solar radiation. Data from WMO (1983). (Data in parentheses are estimates made by the authors.)

Invercargill

| Year | Mean Daily Solar Radiation ($MJm^{-2}$ $day^{-1}$) | | | | | | | | | | | | Annual Total ($MJm^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1981 | 20 | 18 | 13 | 9 | 5 | 4 | 4 | 8 | 11 | 17 | 21 | 21 | 4563 |
| 1982 | 19 | 20 | 13 | 9 | 5 | 5 | 5 | 7 | 12 | 16 | 20 | 22 | 4599 |
| 1983 | 19 | 16 | 11 | 9 | 5 | 4 | 5 | 7 | 10 | 16 | 21 | 21 | 4344 |
| 1984 | | | | | 4 | 4 | 4 | 7 | 12 | 16 | 20 | 20 | |
| 1985 | 18 | 18 | 13 | 8 | 5 | 3 | 4 | | | | | | |

Bismarck

| Year | Mean Daily Solar Radiation ($MJm^{-2}$ $day^{-1}$) | | | | | | | | | | | | Annual Total ($MJm^{-2}$) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | |
| 1974 | 6 | 9 | 12 | 16 | 18 | 27 | 24 | 19 | 16 | 10 | 6 | 5 | 5069 |
| 1975 | 6 | 10 | 14 | 12 | 21 | 24 | (24) | (21) | 16 | 9 | 7 | 5 | (5147) |
| 1976 | 7 | 9 | 14 | 18 | 26 | 25 | 26 | 22 | 18 | 11 | 8 | 5 | 5709 |
| 1977 | 6 | 8 | 12 | 20 | 22 | (25) | 23 | 19 | 12 | 10 | 6 | 4 | (5102) |
| 1978 | (6) | 9 | 15 | 13 | 22 | 26 | 26 | 22 | 16 | 10 | 6 | 5 | (5380) |
| 1979 | 7 | 9 | 14 | 16 | 21 | 25 | 23 | (21) | 17 | 10 | 6 | 5 | (5288) |

Table 5. Comparison of annual sunshine hours at Invercargill, Bismarck and Minneapolis. Data from U.S. National Climatic Center (1976--1979).

Annual Sunshine Hours

| Invercargill | | Bismarck | | Minneapolis | |
|---|---|---|---|---|---|
| Year | Hours | Year | Hours | Year | Hours |
| 1981 | 1499 | 1976 | 2963 | 1976 | 3091 |
| 1982 | 1575 | 1977 | 2632 | 1977 | 2610 |
| 1983 | 1333 | 1978 | 2815 | 1978 | 2848 |
| 1985 | 1675 | 1979 | 2804 | 1979 | 2406 |

The seasonal and interannual variation in RB counts at the overseas sites will now be considered in turn.

### 3.4.1 Daily totals

The seasonal patterns in daily RB counts (Scotto et al., 1976) at Bismarck and Minneapolis are similar to that at Invercargill. However the maximum daily values recorded in summer at Bismarck and Minneapolis are between 8000 and 9000 RB counts per day, which are rather lower than the maximum values of 9000 to 10,000 recorded in summer at Invercargill. This will be due partly to the smaller sun-earth distance for the Southern Hemisphere summer, which at its peak results in the Southern Hemisphere summer receiving 6.6 percent more extraterrestrial solar radiation than the Northern Hemisphere summer and, partly to the lower levels of haze expected in the Invercargill skies relative to most Northern Hemisphere sites. Note that the summer bias due to the sun-earth distance reverses in the winter, so that in winter the Southern Hemisphere receives 6.6 percent less extraterrestrial solar radiation than the Northern Hemisphere winter.

Although individual summer days at Invercargill can have noticeably higher totals, no such relationship is seen for averaged data. The month by month comparison given in Table 6 shows a variable pattern of relationship, undoubtably due to the differing cloud regimes at the three sites. Generally, it is the two Northern Hemisphere sites which receive the greater

totals in summer. By comparison Melbourne receives more UV radiation in summer, and less in winter than its Oakland counterpart (Berger and Urbach, 1982).

Data on the frequency of occurrence of different RB count intensities for Bismarck and Minneapolis (Scotto et al., 1976) are listed in Table 7. There is a close similarity between these and the results from the same analysis for Invercargill (Table 1). Invercargill tends to have more extreme values than either Bismarck or Minneapolis, i.e., Invercargill has slightly more days when very high rates (exceeding 600 RB counts per half-hour) or very low rates (less than 100 RB counts per half-hour) are recorded. This is consistent with the above arguments concerning solar geometry and relative atmospheric haziness, and with the nature of Invercargill's cloudiness.

Table 6. Comparison of Invercargill's average daily RB count by month with the six-year (1974--1979) average daily RB count by month for Bismarck and Minneapolis (Berger and Urbach, 1982). Note, the Berger and Urbach data are given in tenths of Sunburn Units, and at this resolution (44 RB counts) the November to January values for the two American sites are equal.

| | Invercargill | | | | | | Bis. | Min. |
|---|---|---|---|---|---|---|---|---|
| | 1981 | 1982 | 1983 | 1984 | 1985 | | | |
| Jan | | 5761 | 5387 | | 5844 | Jul | 7040 | 6424 |
| Feb | | 5470 | 4627 | | 5245 | Aug | 5500 | 4840 |
| Mar | | 3065 | 2562 | | 3364 | Sep | 3740 | 3256 |
| Apr | | 1438 | 1382 | | 1482 | Oct | 1760 | 1716 |
| May | | 540 | 498 | | 591 | Nov | 704 | 704 |
| Jun | | 305 | 294 | | 324 | Dec | 396 | 396 |
| Jul | | 388 | 359 | | 394 | Jan | 528 | 528 |
| Aug | | 778 | 827 | 801 | | Feb | 1100 | 1056 |
| Sep | | 1740 | 1599 | 1678 | | Mar | 2200 | 1936 |
| Oct | 3292 | 2864 | 3036 | 3100 | | Apr | 3344 | 3256 |
| Nov | 5232 | 4804 | | 5082 | | May | 5236 | 4972 |
| Dec | 6246 | 6019 | 5980 | 6086 | | Jun | 6732 | 6028 |

Table 7. Percentage of year during which intensity value was exceeded for specified number of hours in Bismarck and Minneapolis.

Bismarck

| Half-Hourly Intensity | Never Exceeded | Exceeded 0.5-3 hr | Exceeded 3-6 hours | Exceeded 6+ hours |
|---|---|---|---|---|
| 100 | 29.0 | | | |
| 200 | 47.4 | 10.5 | 18.6 | 23.5 |
| 400 | 67.7 | 14.3 | 18.6 | 0.0 |
| 600 | 94.0 | 6.0 | 0.0 | 0.0 |

Minneapolis

| Half-Hourly Intensity | Never Exceeded | Exceeded 0.5-3 hr | Exceeded 3-6 hours | Exceeded 6+ hours |
|---|---|---|---|---|
| 100 | 27.7 | | | |
| 200 | 46.3 | 14.2 | 18.1 | 21.4 |
| 400 | 69.6 | 16.1 | 14.2 | 0.0 |
| 600 | 95.1 | 4.9 | 0.0 | 0.0 |

### 3.4.2 Annual totals

Berger and Urbach (1982) analysed six years of data from 14 sites in the world network of RB sunburn meters. The annual total RB counts for Bismarck, Minneapolis, Melbourne, and Oakland are shown in Table 8. Invercargill, Bismarck, and Minneapolis all receive comparable annual amounts of UV radiation (about 1 million RB counts), as do Melbourne and Oakland (about 1.5 million RB counts). The northern latitudes of New Zealand might expect comparable results to those of Melbourne, to the extent that the local cloudiness regimes are similar. The data of Berger and Urbach (1982) suggest that, relative to Invercargill, northern New Zealand might expect to receive 30 percent more UV radiation than Invercargill at summer solstice, 50 percent more at the equinoxes, and 100 percent more at the winter solstice.

The interannual variation, represented by the coefficient of variation in Table 8, ranges from 3.4 percent to 7.4 percent. Invercargill's

interannual variation, shown as about 5 percent in Table 3, is within this range. Instrument drift and annual calibration changes may be responsible for a part of the variations. There is, however, a close relationship for Bismarck and Minneapolis between the annual RB counts and the annual sunshine data given in Table 5, and in the case of Minneapolis, the relationship is remarkably linear over a wide range of values, and can account for almost all of its large interannual variation.

Table 8. Comparison of annual RB counts for Bismarck, Minneapolis, Melbourne, and Oakland. The mean, standard deviation and interannual coefficient of variation (in percent) are also given.

| Year | Bismarck | Minneapolis | Melbourne | Oakland |
|---|---|---|---|---|
| 1974 | 1122440 | 1031360 | | 1491680 |
| 1975 | 1059520 | 1056440 | 1496990 | 1492480 |
| 1976 | 1199880 | 1176120 | 1520640 | 1564200 |
| 1977 | 1140920 | 1034400 | 1531200 | 1521080 |
| 1978 | 1187120 | 1102640 | 1401840 | 1550120 |
| 1979 | 1177000 | 942040 | 1502160 | 1422960 |
| mean | 1147960 | 1057320 | 1490720 | 1507440 |
| s.d. | 52360 | 78320 | 51480 | 50600 |
| c.v. | 4.6 | 7.4 | 3.5 | 3.4 |

## 4 ANALYSIS OF DATA - CLEAR SKIES

### 4.1 Zenith angle correction

The spectral response of the instrument does not perfectly match the erythemal response function (Berger, 1976, Berger and Urbach, 1982, DeLuisi

and Harris, 1983), but is shifted towards longer wavelengths by about 10-15 nm (Figure 1). The radiation at these longer wavelengths is much less strongly absorbed by the atmosphere and therefore contributes an increasing and unwanted proportion of the instrument's response as the zenith angle increases. This overestimate is partly compensated by the instrument's imperfect cosine response, in which the instrument response to any beam at incident angle Z to the normal is less than the desired factor of cosine Z (Berger, 1976). The cosine effect error increases with Z.

Berger (1976) examined these error sources, and Berger and Urbach (1982) derived a correction factor as a function of zenith angle for clear skies (see Figure 7). However the correction cannot be applied to cloudy data, and for this reason the results in the other sections of this report, as well as the results from the other sites in the RB sunburn meter network (Berger and Urbach, 1982), have been given in terms of RB counts. Also, at large zenith angles, the correction is large and poorly known (see Figure 7), so the corrected data will be of doubtful quality at the beginning and end of the day, and during the winter.

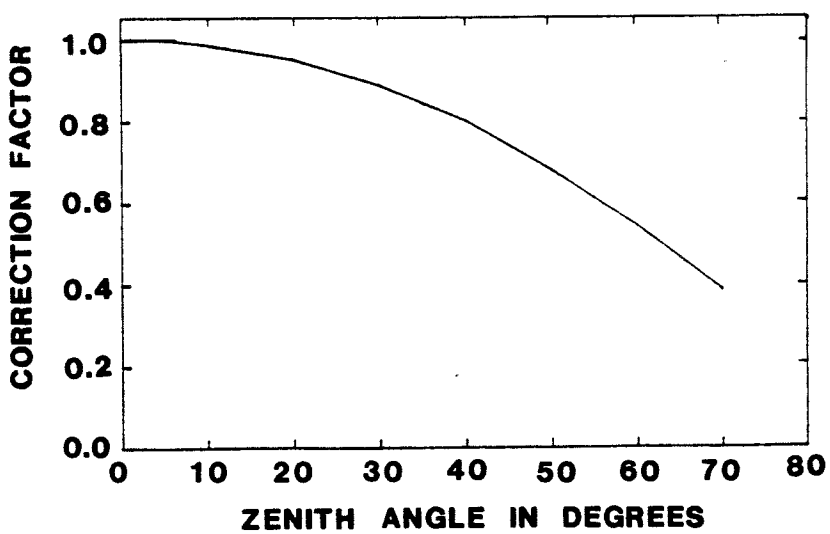


Figure 7. Correction factor for clear sky RB count data which accounts for instrument systematic errors as a function of solar zenith angle.

Corrected clear sky data, which in principle represent true erythemal irradiation, may be expressed in "sunburn units". The "sunburn unit" is defined as equal to the minimal erythemal dose for untanned Caucasian skin exposed to the sun vertically overhead in the tropics (Berger and Urbach, 1982).

The minimal erythemal dose has been equated with an accumulation of 440 RB counts measured under the above tropical conditions (Berger, 1976). However this relation appears to have been used by Berger and Urbach (1982) in their analysis of uncorrected RB sunburn meter data, measured under other conditions, despite the fact that the erythemal content of RB counts varies significantly with zenith angle. For diurnal and seasonal variations this can result in significant errors, but for other purposes it may be acceptable since most of the UV radiation is received when the sun is at the smallest zenith angles, i.e., when the correction factor is closest to unity.

## 4.2 Diurnal and seasonal variation of corrected clear sky data

Very few completely clear days occur in Invercargill. Thirty-eight days with a clear morning and/or afternoon were found, by inspection of solar radiation measurement charts.

The half-hourly RB count data for these days or half days were corrected for the zenith-angle-dependent error and converted to sunburn-unit form by means of the expression

$$S = ( \text{RB count} / 440 ) \cos fZ$$

where Z is the zenith angle for the centre of the half hour, and f is an empirical constant set equal to 0.9. The cosine form and the value of f were chosen as a suitable simple fit of the correction forms found in Berger and Urbach (1982), DeLuisi and Harris (1983) and Basher (1985). At the larger zenith angles, the correction required is very uncertain, and so for $Z > 75^\circ$, cos fZ is arbitrarily set equal to cos f75.

Corrected data for a selection of the days are plotted in Figure 8. The figure shows a more marked contrast between the summer and winter months than was evident in the analysis of uncorrected data (Figure 2). At the height of the summer about six sunburn units are received during the two hours between 1200 and 1400 NZST whereas in winter less than one sunburn unit is received throughout the whole day.

The diurnal variations in corrected data for four clear sky days in February (11/2/82, 23/2/82, 2/2/83, and 17/2/83) are shown in Figure 9. The peak values change dramatically as we progress through the February data, owing to the rapidly changing solar declination, and they also show the effect of ozone differences.

Linear interpolation between the peak values of the three days of near-equal ozone amounts indicates that the peak value for the remaining day, 2/2/83, is about 3.2 percent higher than would be expected if its ozone amount had been 0.293 atm cm. This excess is less than half what would be predicted from applying DeLuisi and Harris' (1983) magnification factor of 1.25 to the ozone deficit of 6 percent, but the difference is comparable with the various uncertainties present.

## 5 SUMMARY OF RESULTS

As expected, the UV radiation measurements of the RB sunburn meter at Invercargill display significant diurnal and seasonal variations. Two-thirds of the annual RB counts are received during the four months November, December, January, and February. Non-zero RB counts are recorded typically for about fifteen hours each day in summer and eight hours each day in winter. On clear summer days about six sunburn units are received in the two hours between 1200 and 1400 NZST, whereas on clear winter days less than one sunburn unit is received throughout the whole day. Since one sunburn unit causes perceptible reddening of untanned skin, this emphasises the risk of sunburn in the summer noon period.

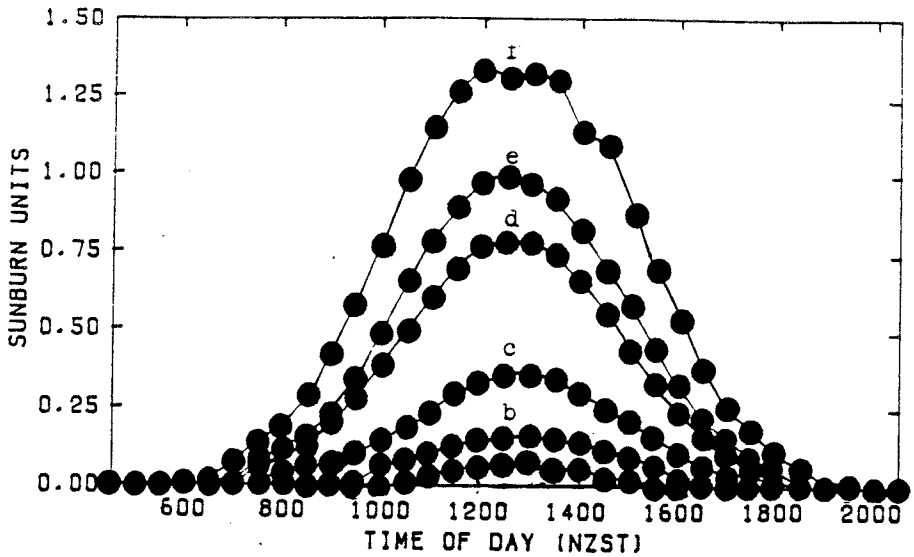


Figure 8. Diurnal variation in half-hourly totals of clear sky erythemal UV radiation (RB count data corrected for zenith angle error), for selected days. Measured ozone amounts are given as X.

(a) 19/ 7/83, X=0.348 (b) 12/ 8/82, X=0.316
(c) 16/ 9/82, X=0.376 (d) 19/10/82, X=0.350
(e) 30/10/82, X=0.347 (f) 1/12/82, X=0.301

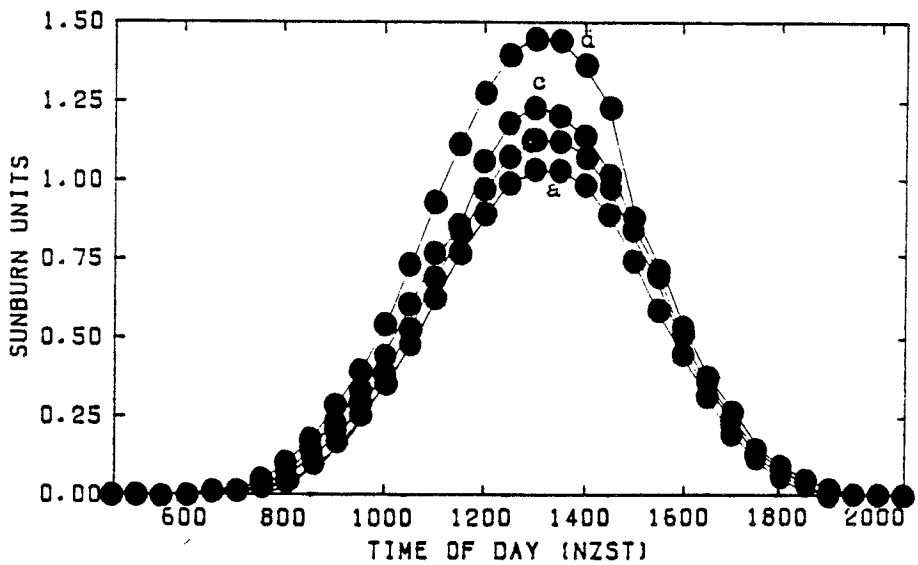


Figure 9. Diurnal variation in half-hourly totals of clear sky erythemal UV radiation (RB count data corrected for zenith angle error), showing effects of seasonal change in zenith angle and of reduced atmospheric ozone on 2/2/83. Measured ozone amounts are given as X.

(a) 23/2/82, X=0.293 (b) 17/2/83, X=0.294
(c) 11/2/82, X=0.294 (d) 2/2/83, X=0.275

There are large variations in RB counts due to changing cloudiness. On a cloudy day, the total count may drop to a sixth of an adjacent clear day's total count, and from year to year there can be a 10 percent variation in the annual RB counts. Day to day and seasonal changes in the column amount of atmospheric ozone will also change the RB count rate by about minus 1-2 percent for each 1 percent increase in ozone.

The Southern Hemisphere summer receives a little higher extraterrestrial UV flux than the Northern Hemisphere summer, owing to the closer sun-earth distance, and Southern Hemisphere skies are expected to be generally clearer than skies at most Northern Hemisphere sites. All other things being equal, this suggests that Invercargill will receive more UV radiation than Northern Hemisphere sites at similar latitudes, and indeed on a few days each year Invercargill does record higher daily RB counts than are ever recorded at Bismarck or Minneapolis.

However, Invercargill's monthly average daily RB counts are generally lower than those of both Bismarck and Minneapolis (comparing like seasonal months rather than calendar months), which can be attributed to Invercargill being cloudier than both Bismarck and Minneapolis.

In general terms the data for the three sites show rather similar behaviour. The same is true of the comparison of Melbourne and Oakland (latitudes 38°). This suggests that the data from Melbourne and Oakland, which give 50 percent higher yearly totals than those at Invercargill, may be taken as approximately representative of the northern latitudes of New Zealand. In conclusion, the measurements of erythemal UV radiation made at Invercargill and elsewhere discount the widely-held popular view that New Zealand has a "harsh" solar UV climate.

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