OZONE, CLOUD, SOLAR AND UV-B LEVELS AT A LOW POLLUTION, SOUTHERN HEMISPHERE, SUB-TROPICAL SITE FOR WINTER/SPRING 1995

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"Abbreviations:" DU, Dobson Units; EST, Eastern Standard Time; SH, southern hemisphere; SD, standard deviation; SR, solar radiation; UV-B, ultraviolet waveband 280-320 nm; UVR, ultraviolet radiation

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ABSTRACT

This paper analyses daily ozone, cloud cover, solar radiation and broadband UV-B data for winter/spring at a low pollution Southern Hemispheric sub-tropical site (27.80°S). The average ozone concentration for the period was 290 DU. An anti-correlation is presented between the ozone and UV-B data over a 5 day period during winter. An ozone deficiency of 45 DU was calculated for the cloud free day on the 16th July, 1995, in which the UV-B level exceeded the clear sky envelope by about 6%. Part of this increase may be attributed to a decrease in cloud cover. In winter, the July average of the daily integrated UV-B irradiance was 29.0 kJ/m^2, (a level which is comparable to that observed in Japan during the summer months).

INTRODUCTION

There are fewer published papers relating to Southern Hemisphere (SH) mid-latitude (30°S to 60°S) ultraviolet radiation (UVR) data than for the equivalent Northern Hemisphere region. This is a direct consequence of reduced landmass in the SH at those latitudes, and hence less suitable measurement sites. There are even fewer published papers relating to SH sub-tropical (23°S to 30°S) UVR data. However, measurements in these regions provide useful information about the effect of ozone depletion on the terrestrial UV levels because a large ozone ‘hole’ exists over the Antarctic sky.

Madronich et al.[1] includes a review of UVR measurements in the SH mid-latitudes, which include Argentina (55°S), Chile (35°S), New Zealand (45°S) and Melbourne (Australia, 38°S). One of the Chile sites of Antofagasta (23°S) is the only sub-tropical site for which UVR data has been published outside of Australia in the SH. Barton[2] includes the UV-B data obtained in Brisbane (27.42°S), a sub-tropical site. After the discovery of ozone depletion in the upper atmosphere, Jaque et al.[3] report of UV-B increases of 50 % through most of Argentina and Chile (53°S to 18°S) over a number of days during the spring of 1993. Australian data presented by Roy et al.[4], Gies et al.[5] and Roy et al.[6] suggested an increase in ambient UV-B levels due to the decrease of the thickness of the ozone layer. Nemeth et al.[7] investigated the effect of weather conditions on UV-B radiation reaching the earth’s surface at Budapest (47°N). Their results show that meteorological factors have a considerable role in the modification of surface measured UV-B levels.

Because interpretation of the measurements at the ground is usually complicated by the presence of tropospheric pollution, few studies have been made to analyse meteorological and UV data. The main objective of this paper is to present calibrated daily broadband UV-B totals at a SH sub-tropical site with low tropospheric pollution. A second objective of this paper is to present data to demonstrate anti-correlations between ozone and UV-B data for the winter/spring period. Previous authors[6] have reported ozone and UV-B anti-correlations in summer, however there have been no reports for the winter/spring period. Relationships of meteorological factors and UVB levels and the implications for humans will be discussed.

MATERIALS AND METHODS

The site at Mt Kent, near Brisbane, Australia (latitude 27.80°S, longitude 151.85°E, altitude 678 m a.s.l.), has a low tropospheric pollution. The site is situated at the subsidence of the Southern Hadley cell and the western arm of the Walker/El-Nino circulation.

UV-B (280-320 nm) raw counts are automatically recorded every 10 minutes by a broadband measurement system[4] supplied by the Australian Radiation Laboratory (ARL) and solar radiation (SR) (400-950 nm), factory calibrated in units of MJ/m^2 with a base integration period of 6 minutes.

Cloud cover (okta) and general weather observations, were recorded by a trained meteorological observer every three hours (except 12 noon), at Toowoomba (676 m a.s.l, 27.6°S, approximately 30 km NNE of Mt Kent) by the methods outlined in WMO[8]. This three hourly data was averaged to give an indication of daily cover. The recorded weather observations were used to check for the occurrence of any unusual weather behaviour on the days of interest. At this time of year, most of the cloud cover characteristics are indicative of a westerly movement of airmass, giving an approximate equivalence in cloud cover between Mt Kent and Toowoomba.

Daily total column ozone in Dobson units (DU) was recorded by a Dobson spectrophotometer at Brisbane (3 m a.s.l., 27.42°S, approximately 100 km east of Mt Kent). This instrument is maintained and calibrated by trained staff of the Bureau of Meteorology. Ozone data was available from June 1st and this was subsequently defined as day number 1. Based on findings from tropical locations, the variation of atmospheric ozone between Mt Kent and Brisbane would be typically less than 1 % and certainly less than the accuracy of the Dobson spectrophotometer.

The UV-B data was calibrated by comparison to a spectroradiometer with calibration traceable to the primary Australian standard lamp housed at the National Measurement Laboratory[9]. The spectroradiometer is based on a dual holographic grating monochromator (model DH10UV, Jobin Yvon Co., France) with the input optics provided by a 15 cm diameter integrating sphere (model OL IS-640, Optronics Laboratories, Orlando, USA). Calibration ratios to obtain the units of J/cm^2 for UV-B from raw counts were calculated from daily totals over four days during winter 1995. Reliable UV-B data was available from June 28th and thus the axes of Figure 1 begin at day number 28.

RESULTS AND DISCUSSION

The uncertainty of each measuring system as well as manual observations is given in Table 1.

TABLE 1. Overall uncertainty of each measurement system, instrument or method

MEASUREMENT SYSTEM	MAIN INSTRUMENT	OVERALL UNCERTAINTY (%)
ARL UV-B unit	International Light sensor (280 to 315 nm)	± 10-20
USQ Solar sensor	Monitor Sensors (400 to 950 nm)	± 10-20
QUT Spectroradiometer unit	Jobin-Yvon double UV monochromator (280 to 400 nm)	± 5
BM Ozone	Dobson spectrophotometer	± 3
BM Cloud Cover	Manual observation	± 1/8 (okta)

Australian Radiation Laboratory (ARL)
Bureau of Meteorology (BM)
Queensland University of Technology (QUT)
University of Southern Queensland (USQ)

The major sources of uncertainty in the broadband UV-B and solar radiation sensors would be the effect of stray light due to imperfect filters and also a less than ideal cosine response. Based on the conclusions of Wong et al.[9] an estimate of the overall uncertainty, including all steps in the calibration process of the UV-B measurements, was less than ± 10 % for the days close to the calibration dates of 27 to 30th July, (day numbers 57 to 60), and progressively increasing to approximately ± 20 % for early winter and late spring. The daily totals of unweighted UV-B (J/cm^2) and SR (MJ/m^2) data were collected between 05:00 and 19:00 Eastern Standard Time (EST).

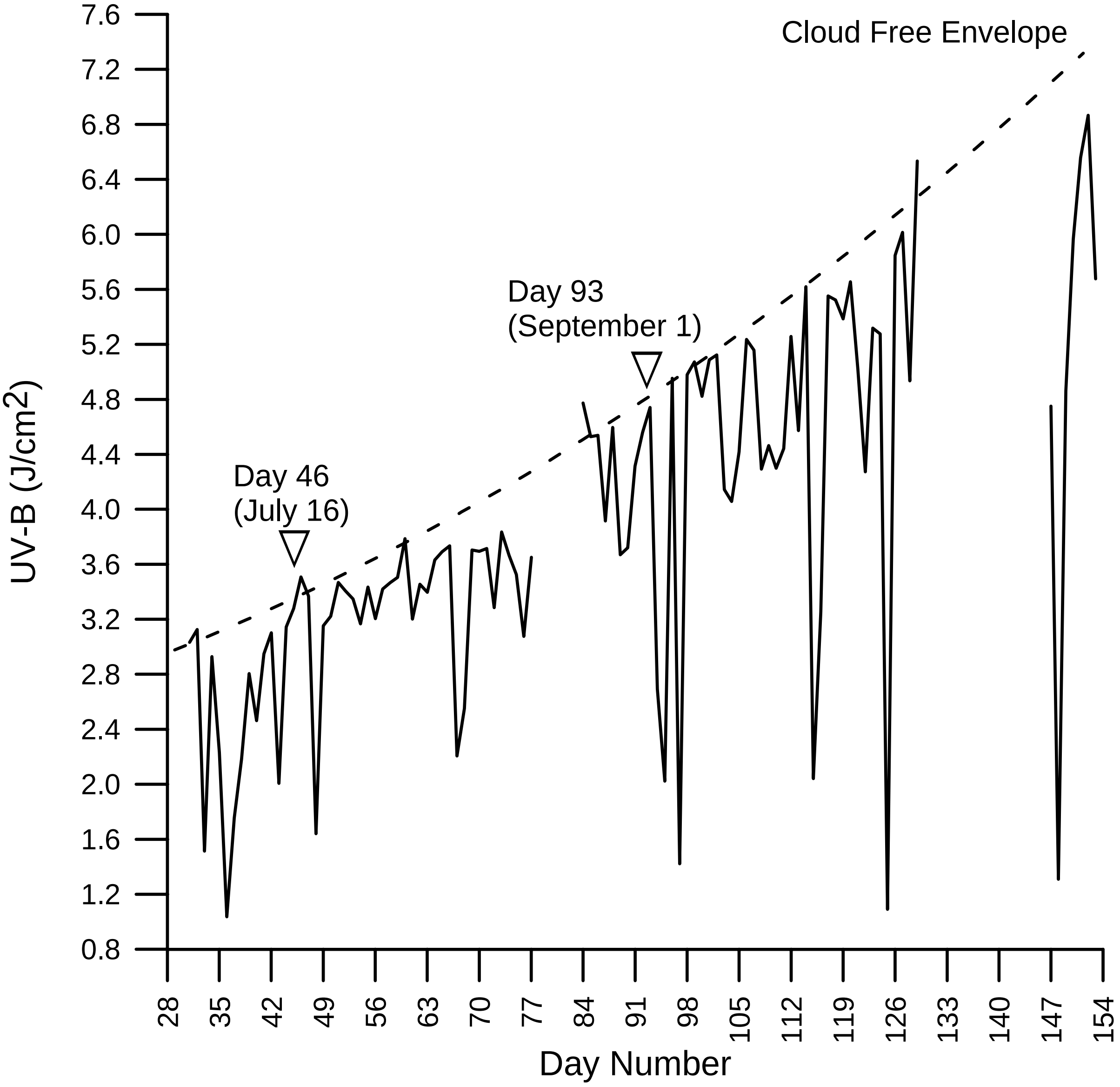

Figure 1. Measured daily totals for UV-B with a cloud free envelope. The horizontal axis is day number, starting from day number 28 (June 28th) to day number 154 (November 1st), 1995.

Figure 1 shows the daily totals of UV-B for winter/spring of 1995 at Mt Kent (day number 28, June 28th, to day number 154, November 1st, 1995). A cloud free envelope (a quadratic with an r^2 of 0.999), is also shown. It was calculated using UV-B data for all Toowoomba cloudfree days (0 okta), with ozone values less than one standard deviation (SD) from the 7 day running average for the winter/spring period. The gaps in the UV-B data are due to either missing data or a saturated detector output which has now been rectified. No unusual weather behaviour was reported on any of the days shown in Figure 1. The full data set represents a precise pattern of the UV-B radiation levels at this location for the winter/spring period. For the winter month of July, the monthly average of the daily integrated UV-B irradiances is 29.0 kJ/m^2.

The daily ozone totals for winter/spring of 1995 at Brisbane were compared to the 7 day running average. In all there were 8 daily ozone values that varied by one or more standard deviations (22 DU), of the winter/spring mean (290 DU), from the 7 day running average (a decrease is defined in this paper as an ozone deficiency). Of these, 7 were ozone increases and one ozone decrease (day 46). Only day number 46 (16th July), was found to have had an ozone decrease greater than one SD. This day was also a cloud free day. The depletion was 7.6 % from the 7 day running average and 15.5 % from the winter/spring average for 1995. Over the 5 day event centred on day 46 (Figure 2), ozone dropped by 14 % between day 43 and day 46.

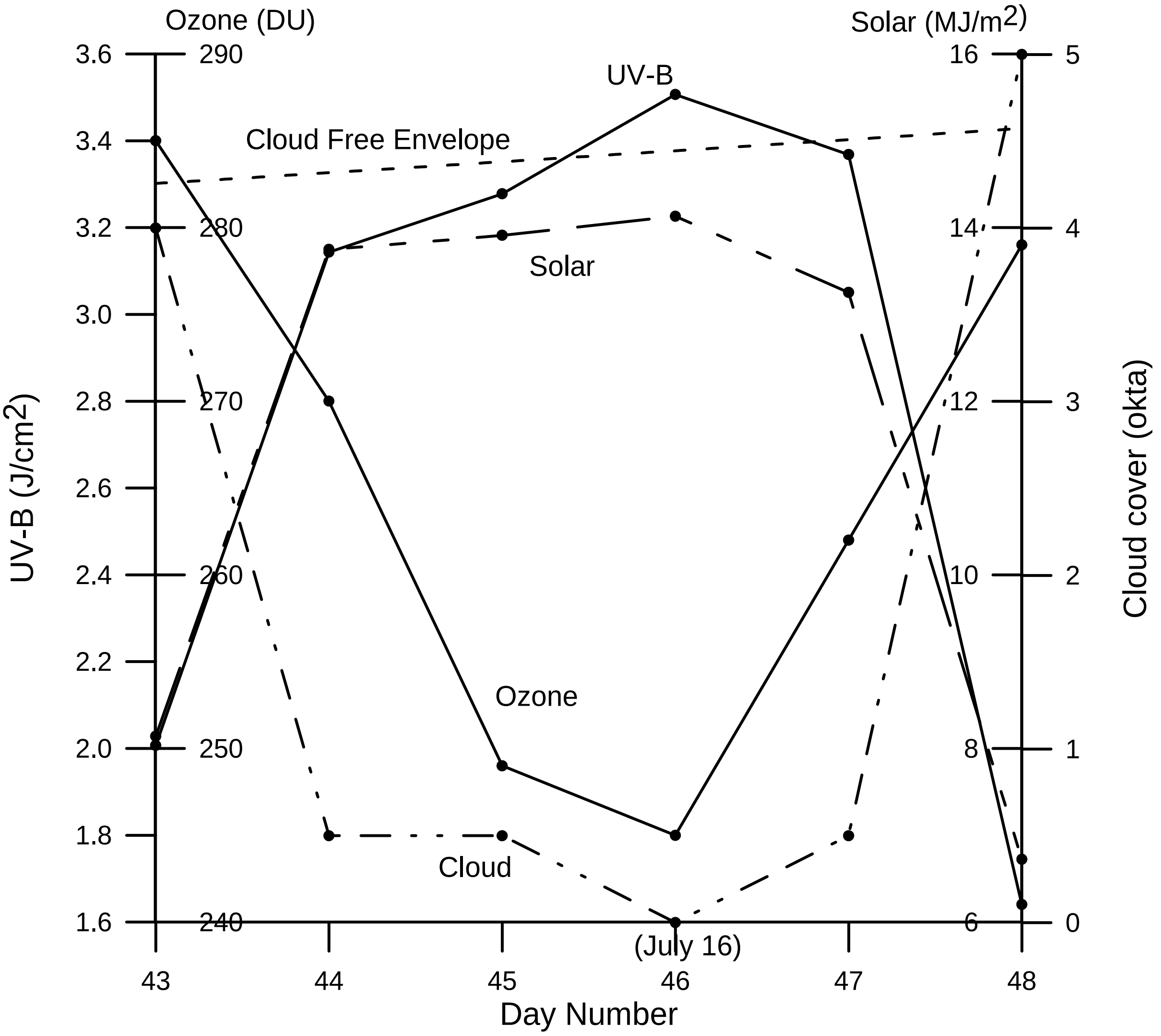

Figure 2. Measured UV-B, SR, ozone and cloud cover for 6 days during mid-winter. The horizontal axis is day number starting from day number 43 (July 13th) to day number 48 (July 18th), 1995. The cloud free envelope is also given.

A ratio of UV-B/SR for clear days, showed two days having a ratio greater than one SD from the mean of the ratio values. SR is not affected significantly by changes in ozone but this is not the case for UV-B (see Blumthaler and Ambach[10]). An increase in the ratio would therefore primarily indicate a reduction in ozone, even though there would be some seasonal dependence. The two days were day 46 (ratio of 0.248), which was also identified from analysis of the ozone averages above, and day 93 (ratio of 0.261) (September 1st), both days are indicated on Figure 1. Over the 5 day event centred on day 93 (Figure 3), the ozone was 5.2 % lower compared to the 7 day running average and 6.6 % less than the winter/spring average.

Figure 2 shows that during the 4 days starting on day 43, the ozone levels (second left scale), decreased by 14 %. The ozone reached a minimum of 245 DU on day number 46. At first sight there does appear to be a significant anti-correlation between ozone and UV-B over this period with UV-B peaking on day 46. However, the behaviour of the SR (first right scale), suggests that most of this increase is related to the reduction of cloud cover over this period. SR has a higher correlation to cloud properties and less to ozone changes compared to UV-B[11]. It is suggested that both the change in the cloud cover and the change in the ozone level contributes to the change in UV-B, however the accuracy of our equipment precludes any definitive statement from our data. It can also be seen that the UV-B level of day 46 exceeds the cloud free envelope. The amount of change of UV-B on day 46, compared to day number 45, is approximately 7 % and may be due to the ozone decrease of 1.6 % (compared to day 45), reaching its lowest value of 245 DU. In an absolute sense this 7 % may not be significant, as it does not exceed the estimated error range of the ± 10 % of the calibrated UV-B data for this time of the year. However as the pattern of the data indicates, there is an increase above the cloud free envelope for this day by about 6 %.

Consequently, although there was a corresponding 7 % increase in UV-B with this ozone decrease, consideration of the meteorological factors at the time show that part of this increase may be attributed to a decrease in cloud cover. In addition, this paper has found that even in winter compared to northern hemisphere mid-latitude sites, Queensland has high ambient levels of UV-B due to both geographic factors and relatively clear and unpolluted skies. For example, Sasaki et al. (1993)[12] measured the monthly average of the daily integrated UV-B irradiances as 29.0 kJ/m^2 and 29.1 kJ/m^2 for July 1991 and 1992 respectively in the northern hemisphere summer at Japan (35^{o}N) compared to the July average of 29.0 kJ/m^2 for winter at the sub-tropical site in this paper.

The risk of developing non melanoma (NMSC) skin cancer is related to the cumulative UV exposure and the risk of melanoma increases with the number of sunburns[13]. Approximately, 800 Australians die annually from melanoma and 200 annually from NMSC[14]. Skin cancer is estimated to cost the Australian community an estimated $400 million per year[15]. In addition, there is the human suffering costs. There is a latitudinal gradient in the incidence rates of NMSC with the rates in latitudes less than 29^{o}S over 4 times the rates in latitudes greater than 37^{o}S[16]. Queensland due to its low latitudes and relatively clear skies has high levels of ambient solar UV and has the highest incidence rates of NMSC and cutaneous malignant melanoma in the world[17]. The high measured UV-B irradiances in this paper show that it is necessary even in winter to minimise UV exposure at sub-tropical locations.

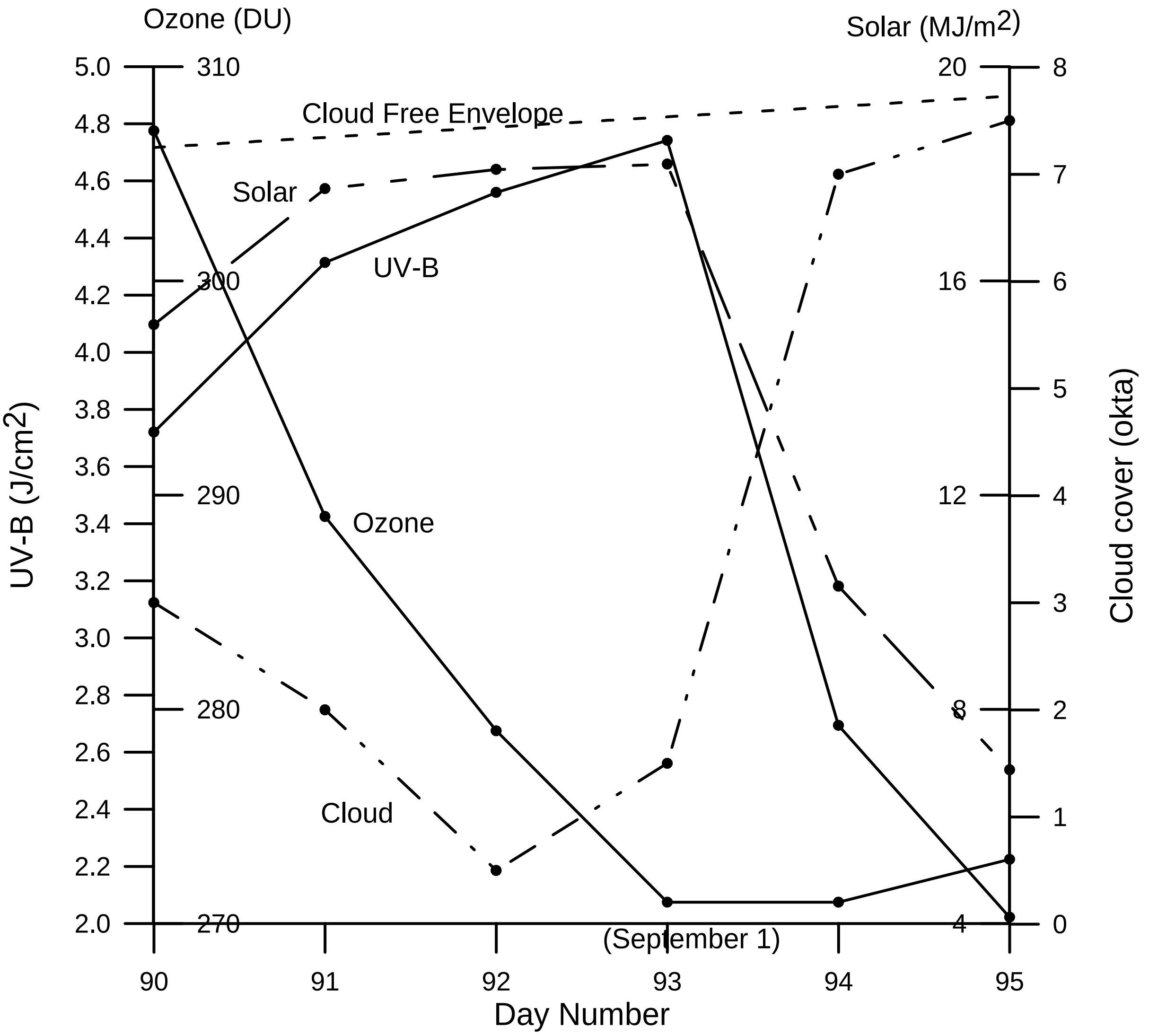

Figure 3. Measured UV-B, SR, ozone and cloud cover for 6 days during late winter/early spring. The horizontal axis is day number starting from day number 90 (August 29th) to day number 95 (September 3rd), 1995. The cloud free envelope is also given.

From the data shown in Figure 3 an average ozone decrease of 11.7 % occurred during the 4 days from 90 to 93, with a minimum of 271 DU on days 93 and 94. The cloud cover was less than 2 okta during days 91 to 93. An apparent anti-correlation exists between the ozone and UV-B changes, but like the case in Figure 2, the rise in UV-B is due predominantly to the drop in cloud cover from day number 90. The SR behaviour, except for days 92 and 93, resembles the UV-B behaviour, and indicates a UV-B change which may be related to ozone levels on days 92 and 93. It should be noted that compared to the example in Figure 2, cloud cover is greater over the 4 days of interest, with the lowest of 0.5 okta, occurring on day 92, when the ozone was still decreasing. Nevertheless, the UV-B/SR ratios were still greater for these two days 92 and 93, compared to day 46. Figure 3 also shows that the UV-B level is below the cloud free envelope for day numbers 92 and 93 as can be seen. This would suggest that cloud cover was not zero on both days, unlike the cloud free case for day 46. Based on the patterns of the UV-B, SR, ozone and cloud cover there would appear to be a speculative anti-correlation between UV-B and ozone on these two days, partly attributed to a decrease in cloud cover

CONCLUSIONS

This paper analyses daily ozone, cloud cover, solar radiation and broadband UV-B data for winter/spring at a low pollution Southern Hemispheric sub-tropical site. The UV-B data presented in this paper is a useful baseline for comparison with future winter/spring periods at SH sub-tropical latitudes. An anti-correlation is presented between the ozone and UV-B data at Mt Kent, over a 5 day period centred on the 16th July. This finding was made possible by including cloud, solar and clear sky UV-B data in the analysis. Although previous anti-correlations have been reported in summer, to the author's knowledge this is the first reported anti-correlation in winter.

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