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MEASUREMENT OF CLOUD ANGLE FOR ENHANCED UVB AT THE EARTH'S SURFACE

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ABSTRACT

This paper presents the results of a four-month study quantifying the effect of cloud and haze on enhanced UVB radiation (310 to 280 nm) using a ground based sky camera system. The sky camera system is the first to measure cloud and haze properties near the sun, in contrast to whole sky assessment. images and radiation data were recorded every 6 minutes at Toowoomba, Australia (27.6 ° S). An image-processing algorithm estimated the amount and brightness of cloud and haze in an angular region of between 12.5 and 35 ° around the sun, as well as the amount of solar obstruction (sun not covered, partially or totally covered). It was found that UVB enhancement greater than 20 % occurred when maximum cloud area was at a 35 ° angle from the sun.

1. Introduction

There has been considerable research into the enhancement of ultraviolet radiation (UVR) reaching the earth's surface as a consequence of a decrease in atmospheric ozone, including anti-correlation during winter in the Southern Hemisphere (Sabburg *et al.,* 1997). The same attention has not been given to the phenomenon of UVR enhancement due to the presence of clouds under certain conditions. Generally, clouds attenuate UVR, but it is explained in the next section how clouds can increase UVR above clear sky levels in some cases. This is an important phenomenon to study, especially as there is a predicted increase in cloud cover associated with the build-up of greenhouse gases. At a World Meteorological Organisation (WMO) meeting of experts on UVR measurement (WMO, 1994), a world standard for reporting the ultraviolet index (UVI) was agreed. It was recognised that cloud information should be included in the UVI forecast. It was stressed that studies focussing on the transmittance of clouds in the UV were required. A specific recommendation was made to have countries present both clear-sky and cloud impacted values on a routine basis. Canada and the United States currently use schemes that provide for cloudy sky forecasts only, however in Australia the clear sky values are given at the same time to allow for local cloud breaks and for the possibility that the cloud forecast was wrong (Rikus, 1996). Further to this, it has been known since at least 1964, that cloudy conditions can reach and often exceed equivalent clear-sky values of UVR under some circumstances.

This paper presents the data collected at southeast Queensland. The effect of cloud amount in an angular region around the sun on the ambient level of UVR is discussed. Cloud angle is defined in steps of ten 2.25 ° sectors (total of 22.5 °), between 12.5 and 35 ° FOV (difference of 22.5 °).

2. Literature Overview

Nack and Green (1974) developed a model, which was adapted by Bodeker and McKenzie (1996), that predicted an increase in UVR for fractional cloud cover over the corresponding clear-sky UVR under special circumstances. An amount of up to 26 % enhancement at 340 nm was in qualitative agreement with earlier experimental results such as Benner (1964) in the Swiss Alps (approximately 47 ° N). A number of recent papers discuss the measurement of enhanced UVR received at the earth's surface under cloudy skies. Mims and Frederick (1994) report of enhanced UVR (at 310 nm) over the maximum solar noon value during fourteen days in 1994 at Hawaii (approximately 19.5 °N) at 2 s intervals. On several days and at various locations around the island, skies partially covered by Cumulus (Cu) cloud, with the sun not obscured ie. Disk Not Obscured (DNO), increased solar UVB by more than 25 % over the expected clear-sky value. The highest cloud induced increase was 29.8 % above that on the previous cloud free day. They also reported that two episodes of increased UVB occurred at or near solar noon and their duration was sufficient to reduce the time required for erythema reddening of exposed human skin by at least 15 % below that expected under an identical ozone column and clear sky. McCormick and Suehrcke (1990) reported measurement of increased instantaneous UVR (400 and 350 nm) of up to 27 %, associated with cloud at Townsville, Australia (19.33 ° S).

Schafer *et al*. (1996) reported enhancement in the range 1 to 11 % for cloud amount of 2 to 9 tenths at Black Mountain, North Carolina (35.66 ° N) every 15 min over a 6 month period. There were also enhancements to near clear sky levels on partly and mostly cloudy days. A ground based whole sky camera was employed at the site to measure cloud amount, type and the degree of solar disk obstruction. These parameters were determined visually from the recorded images by subjective methods. Three of the eighteen enhancements occurred when the sun's disk was not obscured and the remainder for the sun's disk partially obscured (DPO). Similar results were obtained for both UVB (320 to 290 nm) and erythemally weighted UVB.

Lubin and Frederick (1991) reported the roles of ozone and cloud cover on the UVR environment of the Antarctic Peninsula at Palmer Station (64.77 °S). They used hourly ground-based UV measurements with a daily record of sky conditions. They also used a photocell inside a spectroradiometer (SR) to provide a means of verifying the influence of cloud edges. Scattered or broken clouds near the sun acted as extra reflecting surfaces for the direct solar beam, occasionally increasing the surface irradiance to levels higher than would be expected under clear skies. More than 25 % of the irradiance ratios were greater than 1.0 and of these half were greater than 1.1. In contrast, for the overcast skies, fewer than 4 % of the irradiance ratios exceeded 1.0.

Estupinan *et al*. (1996) reported cases of enhanced erythemal UVB (340 to 280 nm), greater than 20 % above normal clear sky values over a 6 month period at North Carolina (approximately 35.7 °N) at 5 min intervals for cloud cover from 5 to 9 tenths. Nearly all increases occurred during the summer afternoons for relatively short periods, less than ten minutes. Cu clouds were found to produce localised increases of UVB radiation of up to 27 % over time scales less than 1 hour under partly cloudy skies and an unblocked sun. Thiel *et al*. (1997) reported enhancements (less than 20 %) of UVR (erythemally weighted in the range, 380 to 280 nm) for 2 to 8 okta of cloud at Garmisch, Germany (47.48 ° N) for 15 min intervals for approximately 3 months. Nemeth *et al.* (1996) reported that when cloud cover was 25 % the UV dose reaching the surface was 15 % higher than in the case of a cloudless sky for solar zenith angle (SZA) greater than 30 °, at Budapest (47.43 ° N). The erythemally weighted UVR (380 to 280 nm) was measured using a UV Biometer at 10 min averages for a 7 month period.

Evans (1994) reported that when there are light clouds such as cirrus, the UVB field could be enhanced by up to 25 %. Rapid variations with enhancements have also been observed with light cumulus clouds. This cloud edge enhancement effect can be explained by Mie scattering. He proposed that jet contrails could increase the UVB exposure levels near large airports. No mention of methodology was given.

Figure 1 The Sun Centred Sky Camera (SCSC) System. The ultraviolet (UV) radiation sensor is situated to the right of the camera, out of view of this picture.

3. Materials and Method

The sun centred sky camera (SCSC) was situated at Toowoomba, Australia (27.6 ° S, 696 m a.s.l.). The level of UVB (310 to 280 nm) and cloud measurements were recorded at the same site for every 6 minute interval over a period of 4 months (September to December 1997), between 9:00 AM and 3:00 PM each day (Figure 1). Daily total column ozone was recorded by a Dobson spectrophotometer to within ± 3

% DU near this site. Accuracy of the UVB ratio (measured UVB divided by clear sky UVB), was within ± 20 % for a SZA range of 25 to 40 ° . The clear sky UVB values were obtained by using the UVB data for a monthly reference clear day and adjusting this data for ozone, sun/earth distance and SZA for the date and time in question. The SZA adjustment was based on a 3rd order polynomial fit to the UVB data of the reference day. The sun/earth adjustment was based on the inverse square law of the UVB data compared to the sun/earth distance of the reference day. The ozone amount was adjusted using the algorithm from Green *et al*. (1974).

The sky camera consisted of a standard video camera and a wide-angle lens. A stepper motor was used to point the camera in the direction of the sun in an east-west direction.

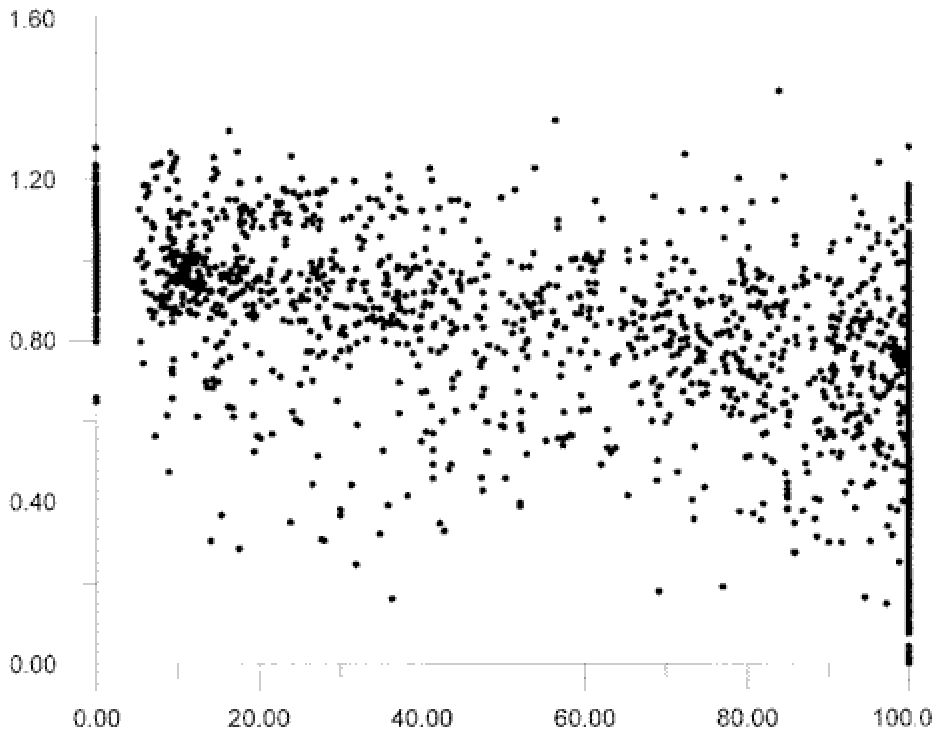

Figure 2 UVB ratio versus cloud amount in the FOV of the camera (CAFOV), for a SZA range of 25 to 40 °.

The altitude angle of the camera was manually adjusted at the end of each week by approximately 2 ° to keep the sun in the centre of the field of view (FOV) of the camera in a north-south direction (Sabburg and Wong, 1997; Sabburg and Wong, 1998). The accuracy of measuring the FOV and angle of maximum area and brightness of the SCSC was approximately ± 2 °.

4. Results

During the 4 month period a total of 5129 images and corresponding UVB data was collected, with solar zenith angle (SZA) ranging from 4.2 to 53.2 °. Of these images, 959 were identified as disk not obscured (DNO), 1240 as disk partially obscured (DPO), 2930 as disk obscured (DO), 689 with cloud amount in the field of view (CAFOV) of 0 to 8 %, 1368 with 8 to 50 %, 672 with 50 to 80 % and 2400 with 80 to 100 %. Twenty-three cases of enhancement greater than 20 % were found using this data, all were occurring during spring months.

Figure 3 CCD image taken by the SCSC on the 20th October 1997 at 2:38 PM. This cloud configuration produced the greatest enhancement of 30 %. This case had a SZA of 38.7 °, a CAFOV of 96.3 %, and an ozone level of 330 DU.

It was determined from clear sky data that the accuracy of the UVB ratio was better than ± 20 % for a SZA range of 25 to 40 °. There were 2377 images in this SZA range, and their corresponding UVB ratio versus CAFOV is shown in Figure 2. When enhancement cases were restricted to this SZA range, six cases were identified. Five of these cases were for an obscured sun and one for partially obscured. It should be noted that all images related to the inclusion of haze as well as cloud in their interpretation, hence the large number of obscured disk cases.

All cases occurred before 10:30 AM or after 2 PM, with a SZA range of 37.9 to 39.7 ° and CAFOV ranging from 16.4 to 96.3 %. The greatest enhancement was 30 %, and occurred at 2:38 PM on the 20th October 1997. This case had a SZA of 38.7 °, a CAFOV of 96.3 % and an ozone level of 330 DU (Figure 3). The UVB counts recorded at this time under the cloudy sky reached 90 % of the noon value for a clear day, one-week later. The smallest enhancement was 20 % for a SZA of 39.7 ° and a CAFOV of 39.3 % (Figure 4).

Figure 4 CCD image taken by the SCSC on the 22nd October 1997 at 9:32 AM. This cloud configuration produced the smallest enhancement of 20 % with a SZA of 39.7 ° and a CAFOV of 39.3 %.

In all cases of UVB enhancement, including the 6 cases with a SZA greater than 40 °, the following conditions were observed:

1. Maximum cloud area was measured at an angle of 35 ° from the sun;
2. Maximum cloud brightness was measured less than 35 ° from the sun and typically at 25 °.

5. Discussion

The results reported in the last section fully support the findings of the papers mentioned in the overview. The fact that the cloud cover is reported in a specific region centred on the sun suggests that this cloud is important in producing UVB enhancements. Further to this it has been found that the greatest enhancements (greater than 20 %), appear to occur when maximum cloud amount exists at an angle of at least 35 ° from the sun. The angle of brightest cloud during UVB enhancement (typically 25 °), would indicate that the enhancement mechanism maybe taking place on the inner side of the cloud, closest to the sun's disk.

Most of the reasons reported for the enhancement of UVR relate to reflections of UVR from cloud surfaces. McCormick and Suehrcke (1990) suggest that enhancement strongly depends on cloud type. They suggest that large Cu clouds with cloud edges several kilometres high are likely to produce strong radiation concentrations. It is not possible to comment on the effect of the height of cloud edges, as this cloud parameter was not measured.

The greatest enhancement (cloud configuration shown in Figure 3) has a large portion of the FOV covered in cloud, and the smallest enhancement (Figure 4) has a large Cu configuration in the upper right of the image. Coupled with the angular information mentioned in the first paragraph, it is possible to make the hypothesis that the enhancement effect may be of a similar nature to the optical phenomenon of a visible sun halo (angle of 22 º), produced by Cirrus (Ci) clouds blocking the sun. In the UVB case it may be due to the presence of haze and or Ci, as this faint cloud was visible around the sun's disk in all of the images producing enhancement, as well as causing the totally and partially blocked sun, DO and DPO. This supports Evans (1994), who suggested that when there are light clouds such as Ci, the UVB field may be enhanced by up to 25 %. Thus, UVB enhancement may be a possible combination of reflection from cloud edges and refraction through the haze and Ci cloud.

The fact that the maximum enhancement occurred for a CAFOV of 96.3 %, supports the comments of Estupinan *et al*. (1996) who suggested that cloud coverage of 80 to 90 % may cause the greatest local UVB increases.

6. Conclusions

By using an automated sun centred sky camera, six cases of UVB enhancement above 20 % have been detected during the morning and afternoon of the spring of 1997 at Toowoomba, Australia (27.6 ° S).

The importance of cloud amount in an angular region of between 12.5 and 35 ° around the sun has been shown. In particular the angle from the sun, at which maximum cloud area occurs during enhancements, was measured to be at the greatest angle of the FOV of the system, 35 °. These results do not preclude that angles could be greater than 35 ° .

The hypothesis that UVB enhancement may be a possible combination of reflection from cloud edges and refraction through haze and Ci cloud near the sun has been made.

The statement by Estupinan *et al*. (1996) suggesting that cloud coverage of 80 to 90 % may cause the greatest local UVB increases has been supported.

We agree with Mims and Frederick (1994) regarding their suggestion that the current forecasting of the UVI is deficient, in that the method does not produce irradiance more than the value for clear skies. The public should be advised that clouds near the sun can significantly intensify UVR under some circumstances, and maximum UV protection should be maintained even on cloudy days.

Abbreviations:

CAFOV - cloud amount in the field of view

Ci - Cirrus

Cu - Cumulus

DNO - Disk Not Obscured

DO - disk obscured

DPO - disk partially obscured

FOV - field of view

SR - spectroradiometer

UVI - ultraviolet index

UVR - ultraviolet radiation

WMO - World Meteorological Organisation

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