# Influence of high levels of cloud cover

# on vitamin D effective and erythemal solar UV irradiances

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Keywords: cloud; vitamin D; UVB; $UV_{D3}$; solar UV

Author Accepted Version of
Parisi, Alfio V. and Turnbull, David J. and Downs, Nathan J. (2012) *Influence of high levels of cloud cover on vitamin D effective and erythemal solar UV irradiances.* Photochemical and Photobiological Sciences, 11 (12). pp. 1855-1859. ISSN 1474-905X,
doi: 10.1039/c2pp25160d

***ABSTRACT*** *The solar irradiances for the initiation of vitamin D synthesis ($UV_{D3}$) have been measured concurrently with the amount of cloud cover to investigate the influence of high cloud cover fraction. The cases of 6.5 and more octa cloud cover were considered for five solar zenith angle (SZA) ranges up to 80$^o$. For each of the SZA ranges, the $UV_{D3}$ reduced due to the high cloud cover. The average of the ratios of the $UV_{D3}$ irradiances on a cloudy day to those on a clear day with the corresponding ozone and SZA are 0.71 for the 6.5-7.5 octa cloud and 0.45 for the more than 7.5 octa cloud ranges. The exposure times necessary to receive 1/3 MED to a horizontal plane were found to increase as the amount of cloud cover increased. For each cloud cover category, the range of values increased with cloud cover and with SZA. This research shows that the current public recommendations on the times of solar UV exposures required to produce adequate vitamin D are inappropriate for situations of more than 6.5 octa cloud.*

## INTRODUCTION

In parallel with the detrimental influence of UV radiation on increasing the risk of human skin cancer and sun-related eye disorders, small amounts of UVB (280-320 nm) exposure are required for the initiation of the synthesis of vitamin $D_3$.[1] The effectiveness of the UV wavelengths for the initiation of vitamin D production is wavelength dependent and is defined by an action spectrum.[2] This action spectrum has a higher relative effectiveness than the erythemal action spectrum between 298 and 315 nm and rapidly drops to zero at 330 nm. This UV radiation waveband acts as an initiator of the synthesis of vitamin $D_3$ for humans by the photolysis of 7-dehydrocholesterol in the skin, to pre-vitamin $D_3$.[3] Vitamin D is essential for the calcium metabolism necessary for good bone development, prevention of rickets in children and osteoporosis, osteomalacia, and fractures in the elderly.[1]

There have been other reported health effects that require further research. These include prevention of insulin dependent diabetes, cancer (for example prostate, breast and colorectal cancer), autoimmune diseases, and multiple sclerosis and other central nervous system diseases.[1,4,5] These show geographic distributions in rate and mortality that may be negatively correlated with the body's vitamin D levels and exposure to solar radiation.

The relationship between the burden of disease and UV exposure displays a minimum risk that represents the optimum UV exposure.[6] Exposures that are well below those for sunburn production are sufficient for the production of the beneficial effects of exposure to UV.[7] The Cancer Council of Australia recommends that during summer, the majority of the Australian population require only several minutes/day exposure to sunlight to an area of skin equivalent to that of the face, hands and arms to produce sufficient vitamin D.[8] However, during winter, it is recommended that higher latitude populations obtain two to three hours of sun exposure over a week.[8] For the parts of the population with skin types V or VI, these times may be three to six times longer.[8-10]

One model that has been proposed for vitamin D production corresponds to an oral intake of 1000 IU of vitamin D and is based on 1/4 MED (minimum erythemal dose) to 25% of the body's skin area.[11] The MED is based on the erythemal action spectrum[12] and is highly influenced by the skin type with one MED taken as 200 $Jm^{-2}$, 250 $Jm^{-2}$, 300 $Jm^{-2}$, 450 $Jm^{-2}$, 600 $Jm^{-2}$ and 1000 $Jm^{-2}$ of erythemal UV for skin types I to VI respectively.[11] Similarly, the times at noon on clear mid summer days to receive an exposure of 1.3 SED (Standard Erythema Dose = 100 $Jm^{-2}$) to a horizontal plane and a vertical plane have been calculated for latitudes from 30$^o$ N to 60$^o$ N and ranged from 16 to 38 minutes.[13] In a shaded environment with more than 40% of sky view, the average times for an exposure of 1/3 MED to a horizontal plane for skin type I ranged from 5.7 min to 22.6 min for a solar zenith angle (SZA) range of 5$^o$ and 65$^o$ respectively.[14]

A position statement by the Working Group of the Australian and New Zealand Bone and Mineral Society, Endocrine Society of Australia and Osteoporosis Australia[15] has determined that 15% of the skin's surface exposed to 1/3 MED will produce 1,000 IU of vitamin D. This Group also advised to avoid deliberate exposure to summer sunshine in Australia for the period that is 2 hours either side of solar noon. Research by Samanek et al.[16] determined that an exposure of 1/6 to 1/3 MED to 15% of the skin's surface for skin type II is sufficient to provide adequate vitamin D synthesis. This research[16] employed the UV index data over a year for major Australian cities to calculate the times to receive exposures of 1/6 and 1/3 MED at the times of 10:00, noon and 15:00.

The amount of solar UV necessary to initiate the synthesis of pre-vitamin $D_3$ is dependent on the local environmental and the behavioural aspects of each person[17]. The recommended times provided in previous research may be influenced by the presence of cloud as cloud cover influences the solar UVB irradiances and will affect vitamin D synthesis.[18] Previous research has shown that cloud cover up to 5.5 octa does not influence to a great extent the biologically effective UV for pre-vitamin $D_3$ production ($UV_{D3}$).[19] This paper will investigate the influence of high levels of cloud cover (7 octa to 8 octa) on $UV_{D3}$ and erythemal UV incident on a horizontal plane.

## MATERIALS AND METHODS

*Concurrent Solar Irradiances and Cloud Data*

The solar spectral irradiances were automatically measured to a horizontal plane and recorded in 0.5 nm increments every five minutes from 0500 to 1900 Australian Eastern Standard Time with a calibrated spectroradiometer (model DTM300, Bentham Instruments, Reading, UK) for nine months from 1 April 2004 to 25 December 2004 at a Southern Hemisphere site at Toowoomba, Australia (27.6$^{o}$ S, $^{o}$ ). The instrument is in an environmentally sealed container that is cooled to maintain a stable temperature at 25 $^{o}$C and is described elsewhere.[20] The data were collected for the full range of cloud cover from zero to eight octa, for all cloud types and for both the cases of the solar disk obscured and not obscured by cloud.

Concurrently, sky images were automatically collected at each five minute interval for solar zenith angles less than 80$^{o}$ with a sky imager (model TSI440, Yankee Environmental Systems, MA, USA). The sky imager records an image of the sky with a field of view of approximately 160$^{o}$. Image analysis software then provides the cloud cover as the amount between 0 and 1 of the sky covered in cloud. Both the unprocessed image and the processed image are recorded. Previous research has found the error in the amount of cloud cover determination to be within ±10% for at least 95% of cases.[21] This amount was converted to the cloud amount in octa in the processing where an octa is defined as the number of eighths of the sky covered in cloud.[22] The cases of 7 octa cloud were taken as covering cases of 6.5 to 7.5 octa; and 8 octa was taken as cases with more than 7.5 octa. For comparison, the cases of no cloud were taken as 0 to 0.5 octa.

The minimum SZA of the data over this period was 4.7$^{o}$ and data for the respective cloud ranges with SZA between this minimum and 80$^{o}$ for the cases when both the spectroradiometer and the sky imager were working was considered in this research. The atmospheric ozone column over the site as provided by satellite data (http://toms.gsfc.nasa.gov/ozone/ozone_v8.html) averaged to 269 Dobson units (DU) with a standard deviation of 22 DU in the nine month study interval.

*Effective UV*

The spectral UV data were weighted with the action spectrum for the formation of 7-dehydrocholesterol to pre-vitamin $D_3$[2] that was linearly interpolated to 0.5 nm intervals. This spectral irradiance data at each 0.5 nm wavelength increment were summed over the wavelength range and multiplied by the wavelength increment to provide the vitamin D effective irradiances ($UV_{D3}$) for each five minute point when the equipment was operational. The erythemal UV irradiances were calculated in a similar manner by weighting the spectra with the erythemal action spectrum.[12] Data were analysed for cases where there were both spectral data and cloud cover data.

The atmospheric column ozone has been taken into account by categorizing the cloud free cases and the cloud cases into the three ozone ranges of ≤255 DU, greater than 255 DU and ≤ 285 DU and greater than 285 DU.[23] The data in each of these three categories represented 31%, 40% and 29% respectively of all the cases. A power function of the air mass ($\cos^{-1}$SZA) was fitted to the clear sky $UV_{D3}$ in each category to enable determination of the clear sky irradiances for the relevant air mass. The functions are $0.757m^{-2.71}$, $0.746m^{-2.75}$ and $0.678m^{-2.91}$ where m is the air mass. This allowed comparison of the irradiances for the high cloud cases to those for the cloud free cases with the corresponding ozone and air mass.

## RESULTS AND DISCUSSION

An example comparison of the vitamin D effective UV to a horizontal plane on a relatively cloud free day and on a day with heavy cloud cover is provided in Figure 1. The two days are in November and the minimum SZA is 8-9$^o$. The average cloud cover during the cloudy day was 8 octa and the ozone was 289 DU and 307 DU for the cloudy and clear days respectively. The relative differences between the two sets of $UV_{D3}$ varies with the changes in the type and possibly thickness of cloud cover during the day. The differences in the ratio of the $UV_{D3}$ for the cloudy case compared to the clear case range from approximately 0.11 at 08:45 to 0.73 at 13:20.

In addition to cloud, SZA has a significant influence on the UV irradiances. In order to account for this, the $UV_{D3}$ irradiances have been averaged for each of the cases of 7 octa and 8 octa cloud for each of the SZA ranges 0-15$^o$, 15.1-30$^o$, 30.1-45$^o$, 45.1-60$^o$ and 60.1-80$^o$ and provided in Figure 2. There are 565 cases in the 7 octa range and 2,367 in the 8 octa range corresponding to 4% and 17% respectively of all the cases where the cloud cover was recorded. The relatively low number of cases with high levels of cloud were due to the drought conditions in 2004. For each SZA range, they are compared to the respective average irradiances for the case of no cloud. The error bars represent the standard deviation of the range of data for each case. For each case, there is a range of irradiances due to the range of atmospheric conditions encountered and the type of cloud cover and whether or not the solar disk was obscured by cloud. However, with the exception of the case for 8 octa cloud in the SZA range of 0-15$^o$, the averages of the irradiances decrease with increasing SZA and they are less for the cloudy cases. For this exception, the average of the irradiances is lower for the 0-15$^o$, compared to the average for the 15.1-30$^o$ range. Differences between the two ranges in the thickness of the cloud cover, the cloud type or whether or not the solar disk was obscured may have caused this result. For the SZA of 0-15$^o$, the average $UV_{D3}$ irradiances drop from 0.61 W/m$^2$ for clear skies to 0.27 W/m$^2$ for 7.5-8 octa. In a similar manner, the averages drop from 0.2 W/m$^2$ for clear skies to 0.1 W/m$^2$ for 7.5-8 octa.

The averages of these $UV_{D3}$ irradiances are approximately 20-25% lower than those reported for the same site over the six month period of January to June 2003[19] covering the mid summer, autumn to mid winter seasons. This difference is due to the data in this current research covering the period from April to December 2004 over the different seasons of mid autumn, winter, spring to mid summer.

The ratio of the $UV_{D3}$ irradiances to the corresponding value for clear skies based on the same SZA and ozone range for each of the SZA categories for the cases of 7 octa and 8 octa cloud cover are provided in Figure 3. The average of the ratios is 0.71 for the 6.5-7.5 octa cloud range and 0.49 for the more than 7.5 octa cloud range.

The average of the times in minutes to receive an exposure of 1/3 MED for skin type I to a horizontal plane for each of the SZA ranges up to $60^o$ for the cloud ranges of no cloud, 6.5–7.5 and 7.5–8 octa of cloud are provided in Figure 4. The error bars are the standard deviation of the data. The SZA range of $60.1\text{-}80^o$ was not considered due to the excessively long times required. The average for the $0\text{-}15^o$ range for no cloud is 3.7 minutes and increases to 12.5 minutes for 8 octa cloud. For the $45.1\text{-}60^o$ range the average is 10.8 minutes for no cloud and increases to 32.9 minutes for 8 octa cloud. As the amount of cloud cover increases for a specific SZA range, the standard deviation for the range of the data increases. In a similar manner, generally as the SZA increases the range of the times for a specific cloud range also increases. These times are for a horizontal plane and will change depending on the orientation of the skin surface relative to the sun and the geometry of the human body. However, they have been provided for the horizontal plane to provide a baseline for the manner in which the times are affected by cloud cover. The times to produce a certain amount of vitamin D will vary for all phototypes with the amount of skin exposed,[24] as well as varying with age and obesity.[25] The percentage of cases in the given time range to receive 1/3 MED compared to the total number of cases in the respective SZA range are presented in Figure 5 for the cases of more than 7.5 octa cloud. For the SZA cases of $0\text{-}15^o$ and $15.1\text{-}30^o$, the majority of the times for an exposure of 1/3 MED fall within the range of less than or equal to 10 minutes with at least 80% of the cases taking less than or equal to 20 minutes. Consequently, even on days with high levels of cloud it is possible when the SZA is less than $30^o$ to receive an erythemal exposure of 1/3 MED to a horizontal plane in 20 minutes or less. The majority of the cases shift to the range of $10<t\leq20$ minutes for SZA of $30.1\text{-}45^o$ and $45.1\text{-}60^o$. For $45.1\text{-}60^o$, there are more cases where the times are in the ranges of more than 20 minutes with 57% in this range. For the cases with SZA of $30^o$ or higher, during high levels of cloud there is a wide range of times to receive 1/3 MED to a horizontal plane and it is not readily possible to provide generalised recommendations to the public on the times required.

## CONCLUSION

The influence on the $UV_{D3}$ irradiances has been investigated for the cases of more than 6.5 octa cloud. There is no information on the type of cloud cover or the thickness of cloud. Both of these may also influence the $UV_{D3}$, however further research is required on obtaining cloud type and thickness from the automatically classified sky images. High levels of cloud cover were found to reduce the $UV_{D3}$ irradiances compared to the corresponding clear sky cases, with a larger reduction for more than 7.5 octa cloud compared to the cases of 6.5-7.5 octa cloud. The average of the ratios of the $UV_{D3}$ irradiances on a cloudy day to those on a clear day with the corresponding ozone and SZA were 0.71 for the 6.5-7.5 octa cloud and 0.45 for the cases with more than 7.5 octa cloud. The times to receive 1/3 MED to a horizontal plane were calculated and for a specific SZA interval the range of the times increases as the amount of cloud cover increases and for a specific cloud range also increases as the SZA increases. The recommendations provided on the amount of solar UV exposures to produce adequate vitamin D are appropriate for relatively clear skies of up to 5.5 octa.[19] However, for the cases where there are high levels of cloud cover there are a wide range of times to receive 1/3 MED and the recommendations on the times of UV exposure may not be applicable for cases of more than 6.5 octa cloud.

*ACKNOWLEDGMENTS**:** The authors acknowledge support from the Faculty of Sciences (USQ) required for maintenance of the equipment used in this research.*

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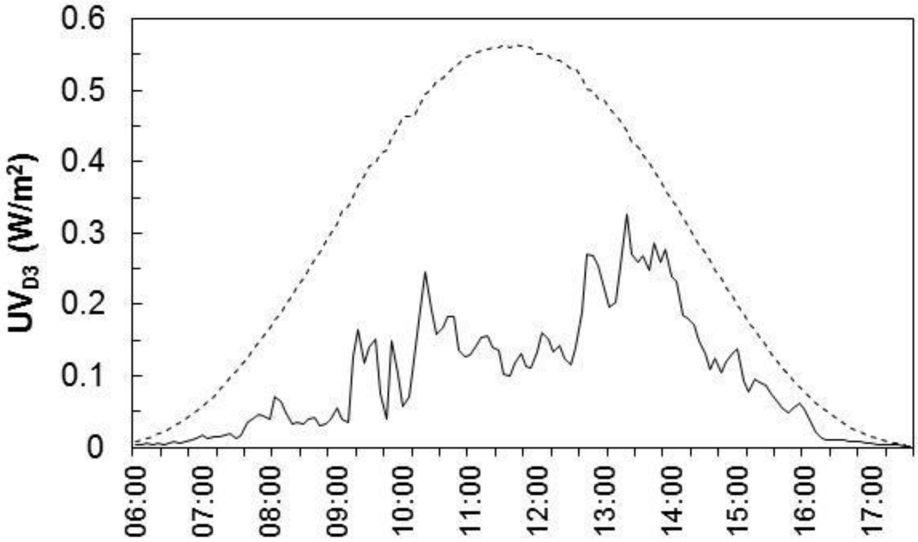


Figure 1 – The vitamin D effective UV on a relatively cloud free day and on a day with heavy cloud cover. The two days are in November and the minimum SZA is 8-9 degrees.

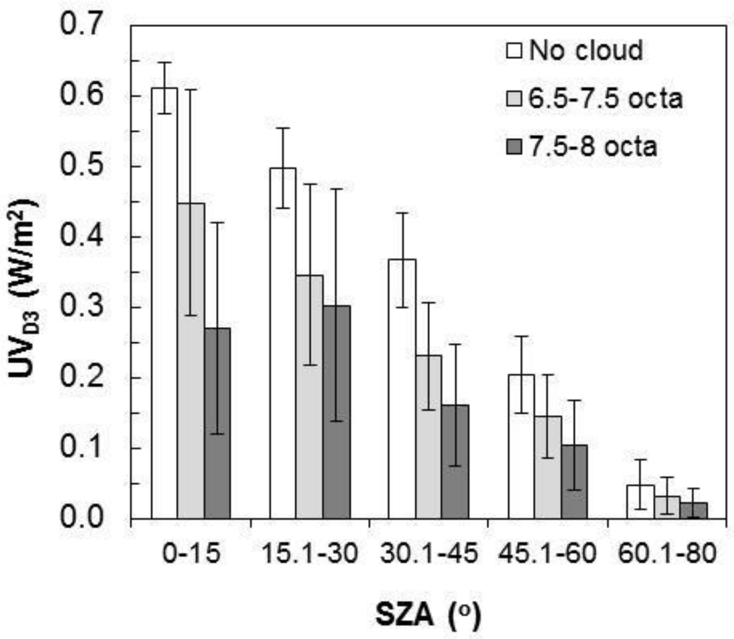


Figure 2 - The mean of the $UV_{D3}$ irradiances for each range of SZA for the cases of no cloud, 6.5–7.5 and more than 7.5 octa of cloud.

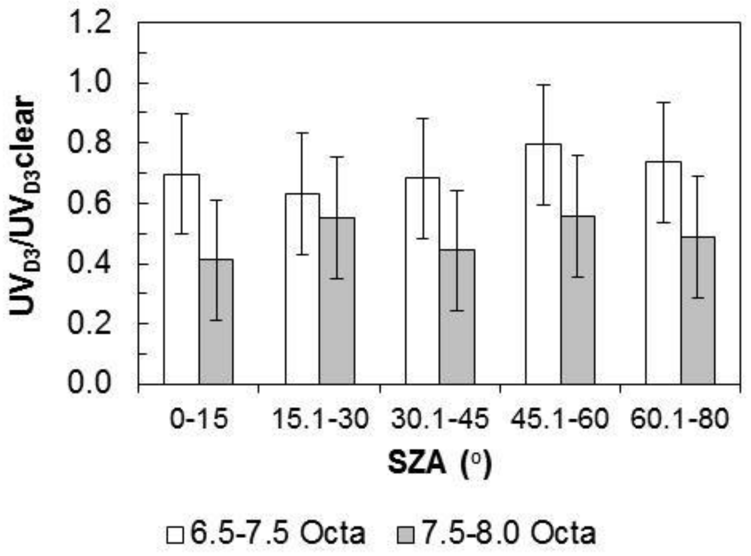


Figure 3 - The ratio of the $UV_{D3}$ to the corresponding value for clear skies for each of the SZA categories for the cloud cover of 6.5-7.5 octa and 7.5-8 octa.

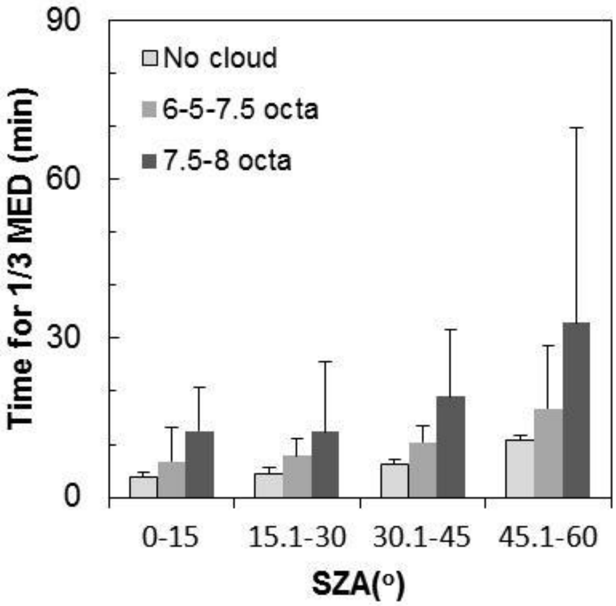


Figure 4 – The time for a horizontal plane exposure of 1/3 MED for each of the SZA ranges for the cloud ranges of no cloud, 6.5–7.5 and 7.5–8 octa of cloud.

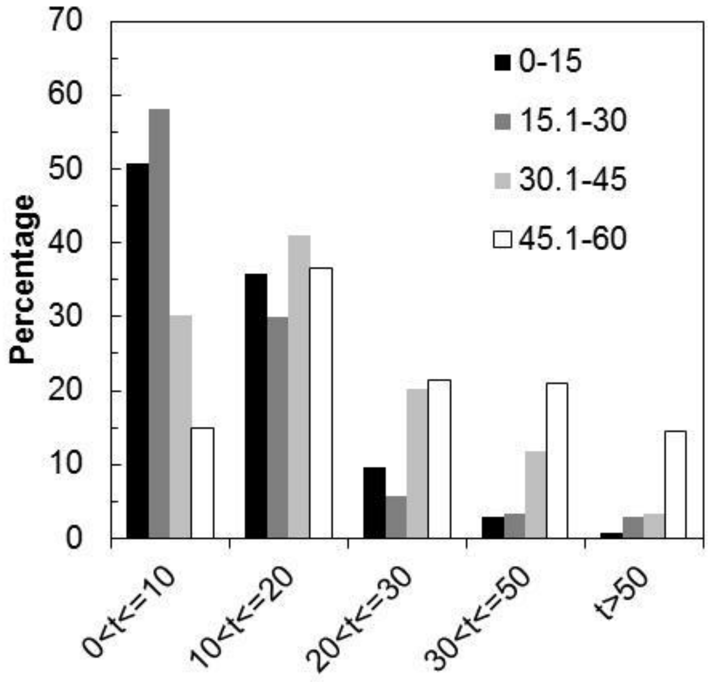


Figure 5 – The percentage of cases in the given time range to receive 1/3 MED compared to the total number of cases in the respective SZA range. All of the data presented are for the cases of more than 7.5 octa cloud.