

Improved method of ultraviolet radiation reflection measurement for non-horizontal urban surfaces

J Turner¹ and AV Parisi

University of Southern Queensland
Toowoomba 4350 QLD
Australia

¹ Corresponding author: joanna.turner@usq.edu.au

Abstract

The technique of ultraviolet reflection ratio measurement is modified from the traditional albedo measurement in order to compensate for unusual inflation of the reflection ratio found previously in non-horizontal surface ultraviolet reflection studies. Data collected to test this method of reflection ratio collection shows there is significant reduction in the inflation. In order to collect UV reflection ratio data on non-horizontal surfaces that can be comparable to differently oriented planar surfaces, the sun and the sensor's positions during the measurement process are equally important, which leads to this new method of reflection measurement for non-horizontal surfaces.

Keywords: reflection ratio, non-horizontal, ultraviolet radiation, albedo

Introduction

All objects and surfaces reflect electromagnetic radiation and therefore visible radiation to some degree. Also ultraviolet (UV) radiation is reflected from most surfaces but because it cannot be "seen" by the human eye it is ignored, at least until the after effect of erythema (sunburn) is detected, which is the most common of sun induced ailments [1]. UV radiation is one of the main factors that contribute to skin cancer induction, and the rate of skin cancer detection is increasing every year [2]. Outdoor workers are considered to be the main affected subjects in urban settings that endure

increased risk of skin cancer due to extended solar UV exposure [3, 4], but with many urban settings incorporating UV reflective surfaces into urban facades, many members of the public may also experience increased risk of skin cancer due to increased solar UV exposure [5].

Reflected electromagnetic radiation is important for UV exposure modeling studies in urban environments, which require information on reflected radiation in order to account for incident irradiance not directly from the sun, such as heat island studies [6, 7] and urban radiation distribution studies [8]. Whilst most of these studies tend towards long wave radiation research, the same modeling tools could potentially be used to create specific shortwave radiation models in order to predict “hot spots” in UV radiation in an urban environment that would be useful in helping the public monitor their UV exposure in the urban environment such as a study by Kumar, Skidmore and Knowles [9].

Unfortunately in the case of both the aforementioned examples of reflected UV radiation a common assumption made in urban models is that UV reflection is given as constant and homogeneous in all directions, exemplified in the case of urban modeling by Fortuniak [10]. The assumption that UV reflection is isotropic and homogeneously distributed from a surface, can be countered from a basic review of atmospheric science theory indicating that no surface can be considered a perfect diffuse reflector (nor perfect absorber), but constitute some combination of the two [11]. The degree to which a surface absorbs or reflects, depends on the medium in question. For visible radiation, this will depend on the colour of a surface, the smoothness of the surface, the density, the type of matter (solid/liquid) and its refractive index (if it is not opaque) whereas reflection of UV radiation is affected by the same factors.

In fact, studies have already shown that UV reflection is not isotropic, such as Weihs [12] who investigated UV exposure received on inclined planes, and mapped directional reflectivity from snow covered surfaces. Additionally, UV radiation reflection is variable depending on the orientation of the surface, the solar zenith angle and solar azimuth angle and the surface type [13]. Computer models that incorporate reflection information in order to create realistic images also provide significant information on radiation reflection behaviour [14-18], namely specular reflection, diffuse reflection and combinations of the two types. Specular reflection occurs when the reflected angle of irradiance is

equivalent to the angle of irradiance incidence [11] known as Fresnel's Law, and the reflection occurs at the boundary of the two media (the medium in which the irradiance is perpetuated and the medium of higher refractive index it encounters). Diffuse reflection occurs when irradiance penetrates the medium of higher refractive index and is backscattered via multiple interactions with the atoms or molecules of the medium. The direction of the backscattered irradiance does not depend on the angle of incidence. In practice, many surfaces are assumed to be perfect Lambertian surfaces and therefore reflection can be approximated on this assumption, but as stated by Weihs [12] most surfaces are not nearly perfect diffuse reflectors or specular reflectors but a combination of the two. This variability due to diffuse and specular reflection requires revision to how we understand UV radiation reflection and equally importantly, the methods used to measure UV reflection.

Defining the problem

Urban settings are comprised of both non-horizontal and horizontal surfaces, and as indicated in the study by Turner et. al [13] the reflective ability of such surfaces is not constant. Minor comments in studies such as Heisler & Grant [8] support this finding by mentioning that some specific urban surface types, such as glass, approach high reflection values at low incident radiation angles.

Traditionally in atmospheric studies the contribution of UV radiation reflected from surfaces to total UV radiation is normally measured by a unit-less quantity called albedo, defined as the ratio of up-welling UV radiation from a horizontal surface to down-welling (referred to as global horizontal irradiance measurement henceforth) UV radiation [19]. In Latin the word albedo means "whiteness" [20]. This suggests that diffuse reflection was the assumed behaviour of UV radiation when reflected from surfaces. This is not technically wrong since albedo studies are classically understood to be a broadband measurement of diffuse reflection from natural surfaces, comparing the integral of the reflected UV radiation to the integral of the incident UV radiation of the radiation spectrum in question for each respective hemisphere [19], and has been used in this fashion since the beginning of the 20th century [21]. Albedo does not generally convey any information about the reflection angle and azimuth [22], which for natural surfaces reflecting diffusely this is not always important. This is because all natural surfaces are rough (even ice) and thus produce diffuse reflection through micro-

roughness following geometrical laws such as the Rayleigh roughness criterion [23]. Despite this, albedo has shown to be inconsistent over areas of terrain with the same surface type [12]. As albedo is supposed to be considered constant from a surface, it is no longer pertinent to describe UV radiation reflection using albedo. Having established changing reflective ratios in Turner, Parisi & Turnbull [13] the next question of the method of reflection measurement arose from investigating the effects on humans due to UV reflected from non-horizontal surfaces [5] therefore implying non-natural surfaces. Research on UV reflection measurements made from non-horizontal planes is minimal. This is surprising considering that there are studies that investigate UV irradiances incident on differently orientated surfaces, which clearly indicate variation between UV radiation insolation on horizontal and sun normal surfaces including Parisi and Kimlin [24] and Philipona, et al. [25]. There are studies that consider the influence albedo has on surrounding horizontal, inclined and vertical surfaces [12, 25-28] and studies on irradiances specifically reaching vertical surfaces [28, 29]. This may simply be due to the assumption that reflection is isotropic and homogeneous as previously discussed. However, by considering seasonal reflective measurements made by Rosenthal et al., [30] reflectance on a horizontal surface is shown to be not consistent through seasons with differing reflective measurements obtained for grass and water. Weihs [12] through modeled data and bi-directional reflection measurements supports this variability, leading to work carried out to show that reflectance is not constant for more urbanised surfaces [13] where reflection of UV radiation in a solar UV environment is dependent on solar zenith angle (SZA), solar azimuth angle (SAA), orientation and of course, surface type.

In the aforementioned study [13], which investigated the reflection from horizontal, inclined and vertical surfaces, some peculiarities were observed within the data obtained using the standard technique of reflection/albedo measurement. These were identified by the anomalous values of reflective quantities at specific sections in the UV spectrum at equal to or greater than unity at specific SZA and SAA orientations. No surface can reflect more radiation than is incident upon it, otherwise the surface must also be considered an emitter of the same wavelengths of radiation. Due to the metal surface types used, it is unlikely this would happen since it is known that shiny metals are exceedingly poor emitters but good reflectors. This paper will establish specifically the cause for these unusual

measurement values through measurement technique, provide data to support this revision and present a revised process in order to obtain appropriate reflection measurement values for non-horizontal surfaces.

Methodology

Revising the methodology

Measurements made in the study by Turner et al. [13] were carried out using the traditional reflection measurement method as established in the introduction, comparing the measured reflected irradiance to the measured global horizontal UV irradiance. For inclined and vertical surfaces, the reflected irradiance was measured by orienting the sensor normal to the plane of investigation to account for all reflected UV irradiance, in order to compare to the global horizontal measurement. However with SZA and SAA as main contributing variables to UV reflection on a man-made surface, this technique does not take into account an important factor that governs atmospheric UV radiation research. Specifically this is the proportion of direct to diffuse irradiance that reaches the earth's surface or any differently oriented planar surface. Direct UV irradiance takes the shortest path through the earth's atmosphere (a "direct" path) and diffuse UV irradiance will take a longer indirect path through the atmosphere, and can strike a surface from almost any direction. Direct UV irradiance is strongly dependent on the positioning of the sun in the sky, and therefore dependent on the SZA and SAA. Diffuse UV irradiance is less dependent on the SZA and SAA, but still influenced by these factors, as the irradiance is scattered and reflected from components in the atmosphere, and therefore has no particular direction of origin that the irradiance may come from. For differently oriented planar surfaces, UV irradiance striking a surface varies with SZA and SAA and therefore direct and diffuse UV constituents, as shown by work carried out by Webb et al. [29] on vertical surfaces. Therefore both components of solar UV irradiance are equally important to total amount of UV irradiance in measurement of reflection, however the global horizontal solar UV irradiance measurement used as a frame of reference for the method of reflection measurement (specifically for vertical or inclined surfaces) fails to take into account the variable nature of direct and diffuse UV irradiance at extreme SZA and SAA. This problem is best portrayed visually and is shown in Figure 1.

A global horizontal UV irradiance measurement made when the sun is at large SZA, means that the measurement will be proportionally dominated by diffuse UV irradiance, with the proportion of total direct UV irradiance minimized by the visible or effective area of the sensor to the sun (see Figure 2). For a UV reflection measurement from a horizontal surface, the horizontal orientation of the sensor will provide a comparative measurement, as the same proportions of direct and diffuse UV irradiance in the reflected UV irradiance will be detected due to the same effective area of the plane of the horizontal surface for each component of the reflection ratio measurement. For a vertical or inclined surface when the sun is at a large SZA, with walls oriented towards the sun at large SZA, the global horizontal UV irradiance measurement will be proportionally higher in diffuse UV irradiance to direct UV irradiance, compared to the reflected irradiance measurement with the sensor perpendicular to the reflecting plane. This will be the opposite for the UV irradiance striking the vertical or inclined plane with proportionally higher direct UV to diffuse UV resulting from the changed effective area of the sensor. As a result, if the proportion of direct UV irradiance is higher on a non-horizontal surface than a horizontal surface (which is being used as the comparative frame of reference) the corresponding reflection ratio derived will be artificially inflated due to a lower proportion of direct UV irradiance which corresponds to the increased proportion of effective surface area of the sensor compared to the lower effective surface area of the horizontal sensor measurement. This reasoning explains the spectral UV reflection measurements that appear at levels higher than unity in the study by Turner et al. [13]. It is recommended that a frame of reference that maximizes direct UV irradiance at all SZA should be used instead. This frame of reference is more appropriate due to the difference between specular and diffuse radiation reflection properties. Specular reflection tends to dominate metallic shiny surfaces compared to diffuse reflection, and diffuse reflection from such surfaces in general can be attributed to microrough surfaces, which reflect specularly but appear diffuse in the macro scale. Specular reflection results from incident irradiance consistently from the same direction and is therefore measurable in the macro scale. When the frame of reference solar measurement is made by orienting the sensor towards the solar position, direct UV irradiance is maximized, and this is true for all measurements at varying SZA. This new frame of reference measurement is referred to as a direct normal UV irradiance measurement.

To test the hypothesis that the above provides an improved technique for reflection measurements from a non-horizontal surface, a number of spectral UV reflection measurements from vertical, horizontal and inclined surfaces were conducted using two reference parameters: a global horizontal UV irradiance measurement, and a direct normal solar UV irradiance measurement. This second method's reference parameter provides a maximum effective surface area for detection of direct UV irradiance when measuring from each surface and sensor orientation.

Testing the Methodology

The UV irradiance and reflection UV irradiance measurements were made using a USB4000 Plug-and-play Miniature fibre optic spectrometer with a cosine corrected [31] input diffuser (Ocean Optics, Inc., USA). The USB4000 spectrometer has a bandwidth of 200 nm to 850 nm, with a 600 line blazed grating, a blaze wavelength of 400 nm and an opening slit width of 25 μm . As a result of these specifications the spectrometer measures in average integrated steps of 0.2 nm. The integration time was 20 ms and averaged over 20 scans. When used for spectral magnitude measurements, the USB4000 is calibrated to a NIST traceable scanning spectroradiometer (Bentham model DTM300, Bentham Instruments, Reading, UK) using a calculated calibration factor. The variance between the measurements made by the calibrated USB4000 and the Bentham has been found to have an uncertainty of $\pm 10\%$ across the spectrum and daily SZA range. Stray light reductions can be carried out by correlation with higher wavelength spectral counts [32] or matrix methods [33]. The surface type used to investigate the measurement technique was zinc aluminium coated steel trapezoidal profile surface, commonly used in industrial and some residential building. After production, the surface is shiny and smooth and generally remains in this form until weathering adds sediment and damage over time. The trapezoidal profile has a height difference between the top and bottom of each ridge of 2.9 cm and the distance between the centre of each ridge is 19 cm (a paint coated version is visible in Figure 1) [5,13]. The ridges are equally spaced across the surface and are symmetrical. The surface ridges were aligned top to bottom for inclined and vertical surfaces which holds with general building practices, and north to south for the horizontal surface. These ridges have been previously

shown to not cause significant variation in reflection from this surface type [34]. This surface is a known UV radiation reflector [5, 13], with a coating of combined zinc and aluminium increasing the reflectivity of the steel. Galvanised steel (zinc coated) surfaces are more highly reflecting but tend to be used much less in building practises due to cost differences.

The spectral UV irradiance measurements were carried out on 11 September, 2011 from 8 am to noon, with a range of 63.3° , 68.5° to 32.4° , 354.1° (SZA,SAA). The following specific measurements were recorded: global horizontal UV irradiance, direct normal UV irradiance, and reflected UV irradiance from north facing vertical, inclined (35°) and horizontal surfaces. Each of the measurements was carried out in close succession every ten minutes over the range of SZA and SAA indicated, resulting in a minimum of twenty-four measurements for each measurement type. The measurements were then compiled and the spectral UV reflection ratio for each of the vertical, horizontal and inclined surfaces were calculated using both the global horizontal UV irradiance measurement and the direct normal UV irradiance measurement as reference parameters. For the entire range of data collected for each surface orientation and for each reference parameter, the average daily spectral UV reflection ratio, the minimum daily spectral UV reflection ratio and the maximum daily spectral UV reflection ratio were calculated. The difference between the reflection ratio of global horizontal UV irradiance, and reflection ratio of direct normal UV irradiance were compared by plotting the factor difference between reflection ratios for the average daily spectral UV reflection ratio, the minimum daily spectral UV reflection ratio and the maximum daily spectral UV reflection ratio. This was calculated at each integrated step by dividing the global horizontal reflected ratio by the direct normal reflected ratio.

In addition to visually comparing the data, the data was compared using IBM SPSS Statistics 19 software to determine if the different measurement techniques result in a statistically significantly different result. The data was analysed at a 95% confidence interval using a one way ANOVA. It was hypothesized that the direct normal reflection ratio would be statistically different to the global horizontal reflection ratio for a vertical surface.

Results

Figures 3 to 8 show the results of calculating the average daily spectral UV reflection ratio, the minimum daily spectral UV reflection ratio and the maximum daily spectral UV reflection ratio for the two reference parameters, global horizontal UV irradiance and direct normal UV irradiance for a vertical surface (Figure 3), horizontal surface (Figure 5) and an inclined surface (Figure 7). The factor difference between the reflection ratios for the two reference parameters is shown for a vertical surface (Figure 4), a horizontal surface (Figure 6) and an inclined surface (Figure 8). In the investigated average, minimum and maximum reflection ratios for Figures 3, 5 and 7, it is shown that a global horizontal reflection ratio exceeds the direct normal reflection ratio. By comparing the factor difference between averages for each surface orientation, it is seen that for horizontal (Figure 6) and inclined surfaces (Figure 8), the factor difference can range from 10% to 40% higher reflected ratios using the global horizontal UV irradiance, but for the vertical surface (Figure 4), the average ranges from 15% to 50% higher factor differences.

For the statistical analysis (Table 1), it was found for the direct normal reflection ratio compared to global horizontal reflection ratio for the average of the vertical surface, that the difference between the two types of measurement were statistically significant, resulting in an F-value of 156 and a significance level of much less than 0.05. Statistical significance is determined to be present when the significance level is less than 0.05 (5%) for a 95% confidence interval. For the minimum and maximum values for a vertical surface, the F-values were 89.4 and 404.5 respectively. Despite the apparent differences in the graphical presentations, there was some expectation that no statistical difference between direct normal reflection ratios and global normal reflection ratios would be observed due to the inclined surface (35°) and horizontal surface would have direct normal reflection ratios that would be more similar to global horizontal reflection ratios from the lower dissimilarity between surface planes. However this proved to not be the case, with statistically significant differences determined for both the inclined and horizontal surfaces, for average, minimum and maximum values. A second data analysis was carried out for specific SZA and SAA grouping, namely large SZA and medium to small SZA, to determine if the averaging process created factors that affected comparison statistically (Table 2).

Discussion

The presented data (Figures 3, 5, 7) clearly indicate that using the new frame of reference (direct normal rather than global horizontal) reduces the reflection ratio obtained per wavelength for all differently oriented planar surfaces. In addition, the new frame of reference clearly removes any reflection ratios exceeding unity, indicating that the direct normal reflection ratio is most likely a more representative value for reflection from this surface type. In Figure 5 (horizontal) we see the general spread of reflection ratios over the SZA range of the day does not change dramatically from a global horizontal reference to a direct normal reference, instead a shift of 0.05 to 0.1 in the reflection ratio over all SZA is apparent for the entire UV spectrum presented. Figure 7 (inclined) shows a decrease in the general spread of direct normal reflection ratios compared to global horizontal, and the overall spread increases within increasing wavelength. Interestingly Figure 3 (vertical) shows a very different change in spread over varying SZA. The direct normal reflection ratio changes significantly from the global horizontal reflection ratio and the overall spread for the reflection ratio over the day decreases with increasing wavelength. This no doubt explains the large factor difference in Figure 4 compared to the horizontal (Figure 6) and inclined (Figure 8) factor differences which are relatively consistent for minimum, average and maximum daily spectral reflection ratios. It was important to establish if the data from global horizontal reflection ratios was statistically significantly different from direct normal reflection ratios rather than simply visibly observed to be different (which does not necessarily imply there will always be a statistical difference) to confirm that the new measurement technique provides different information to the original measurement technique. In statistical analysis, the significance level is used to indicate if there is any significant statistical difference between two or more groups of data. The significance level depends on the confidence interval being used for the test and the resulting F-score, and in the case of a 95% confidence interval (standard), a score below 0.05 indicates significance, the smaller the significance level, the more significant the difference becomes. Table 1 displays the F-values and significance levels, indicating that the data is statistically significant for a 95% confidence interval with all significance levels below 0.05. As these differences were obtained for only averages, minima and maxima, a second data analysis was carried out for specific SZA and SAA grouping, namely large SZA and medium to small SZA. The results displayed

in Table 2 indicate that for the specific SZA and SAA groups, there is statistically significant difference between the global horizontal and direct normal reflection ratios.

It is particularly interesting to look at the reflection ratios for the vertical and horizontal surfaces together. Figure 9 compares the direct normal reflection ratio for horizontal and vertical surfaces. The average reflection ratio for horizontal and vertical surfaces differ more in the longer UVA wavelengths compared to the more similar reflection ratios in the UVB wavelengths (as indicated by the percentage variance). It is possible that this is an artifact of the changing of the detection of the diffuse UV. Since UVB radiation is scattered proportionally more than UVA radiation, for both vertical and horizontal surfaces, the strong scattering in all directions coupled with the direct UVB reflection results in a relatively similar result regardless that the sensor is oriented differently for each appropriate measurement. However, UVA radiation scatters proportionally less than UVB, and the position of the sensor when measuring reflection will show proportionally less UVA according the degree of scattering. What this means for a vertical surface in the UVB spectrum, the sensor is oriented normal to a vertical plane and despite blocking some diffuse UVB irradiance, the overall UVB radiation scattering is enough to produce relatively similar results. UVA radiation on the other hand, scatters relatively less and with a small distance from a surface, a sensor will detect less UVA irradiance in total compared to a measurement where the sensor is oriented in the global horizontal position, due to the lower level of scattering. Therefore, the aspect of increasing direct UV irradiance detection in the modified reflection ratio technique has reduced the diffuse UV irradiance detection in non-horizontal surface reflection ratios.

The discussion on specular and diffuse reflection presented earlier in the literature may have intimated that perhaps this reflection ratio measurement technique is more specifically required for measurements from man-made surfaces only. This would appear to imply surfaces (when newly created) that are in nature uniform and smooth, suggesting any man made surface will ensure specular rather than diffuse reflection. However, according to Berdahl & Bretz [35] the smoothness or roughness of the surface is not always so clear cut, citing that (for example) a smooth white coating is

actually rough on the scale of the wavelength of light, resulting in a white surface rather than a glossy or mirror-like surface. For man-made surfaces using metals or similar substances, the particles are relatively closer to the size of the wavelength of UV radiation or visible radiation, making their reflective capability relatively high [14]. A coating of white paint over a metallic surface will immediately reduce the reflectivity of such a surface as indicated by the initial study by Turner et al. [13]. However this study shows a paint coated surface also undergoes the same issues that the metal surface did in this study and reflectivity still depends on the sensor and the position of the sun in the sky. So a much less reflective surface still has variable reflectivity due to the position in the sun in the sky. If this surface should also happen to be naturally formed rather than man-made, then it is just as important that the adjusted reflection measurement as recommended in this study should be used for natural surfaces as well as man-made surfaces. The study by Weihs [12] enforces this recommendation, where variation in topographical UV reflection from ground surfaces is clearly mapped out. That study compared the influence of reflected UV irradiance from non-horizontal surfaces, yet the data within the paper clearly shows variable reflection values from a natural surface. Therefore, it raises the question on whether the traditional method of reflection measurement in the UV spectrum (albedo) should be adhered to in all UV reflection measurements. The information found in this study suggests that for specific surface analysis, and for specific influence on human forms or simulation models, the method of traditional albedo measurement should be replaced with the reflection method described in this paper to ensure a more accurate representation of reflected UV radiation.

Conclusion

This study has shown that the technique of reflection measurement from urban or man-made surfaces when based upon traditional reflection ratio measurements such as albedo, overestimate the reflective capacity of a surface, as indicated by reflection measurements from surfaces at large SZA and SAA exceeding unity. When measuring reflection from various planes of the surfaces being investigated, it has been shown that the frame of reference for incoming UV irradiance must account for the maximum direct UV irradiance from the sun by directing all reference measurements towards the

solar position, due to specular reflection acting as a strong contributor to UV reflection from urban or man-made surfaces. Artificially inflated reflection ratios can occur if these aspects are not taken into account. It is recommended that for man-made and even natural non horizontal surfaces, this new method of UV reflection measurement is used to measure UV reflection for specific surface analysis (over short distances) rather than the traditional method of albedo measurement.

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Figure 9 – Comparison of spectral UV direct normal reflection ratio for horizontal and vertical surfaces with absolute and percentage variances.

Table 1 – Table of F-values and significance (Sig.) levels obtained for one way ANOVA analysis of data.

	F	Sig.
Inclined average	743.1	.000
Inclined minimum	121.0	.000
Inclined maximum	484.8	.000
Vertical average	156.0	.000
Vertical minimum	89.4	.000
Vertical maximum	404.5	.000
Horizontal average	233.7	.000
Horizontal minimum	138.8	.000
Horizontal maximum	118.6	.000

Table 2 - Table of F-values and significance (Sig.) levels obtained for one way ANOVA analysis of data for early morning measurement (62.7, 68) and a solar noon measurement (32.3, 3.9).

	F	Sig.
Vertical early	465.2	.000
Horizontal early	271.9	.000
Inclined early	423.0	.000
Vertical noon	67.1	.000
Horizontal noon	538.1	.000
Inclined noon	1252.3	.000

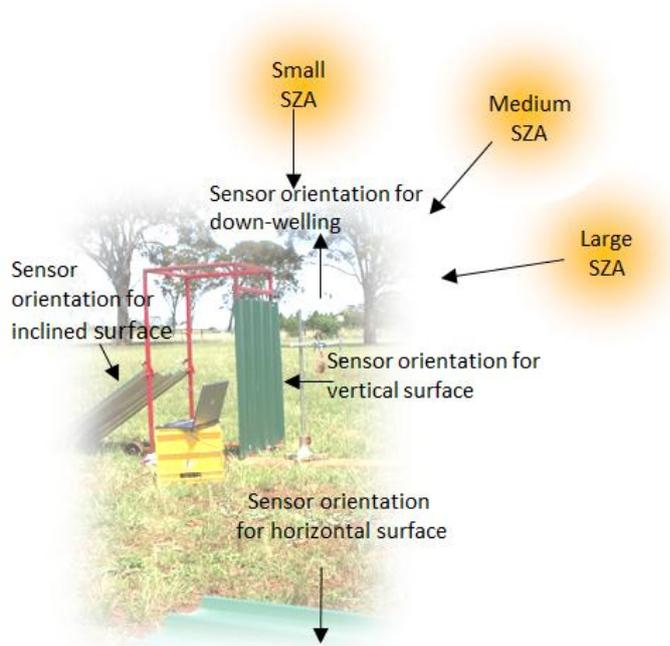


Figure 1 - Orientations of the sensor for global irradiance measurements and reflected spectral measurements from different surface inclinations, relative to the position of the sun.

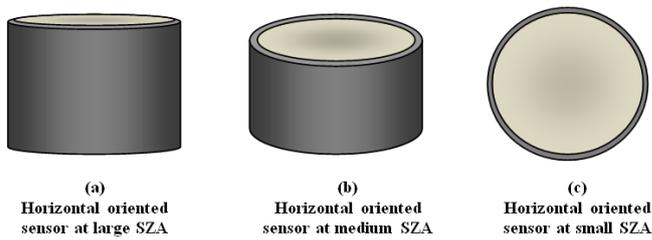


Figure 2 - Approximate surface areas exposed to UV irradiance from global (down welling) irradiance measurements relative to different SZA.

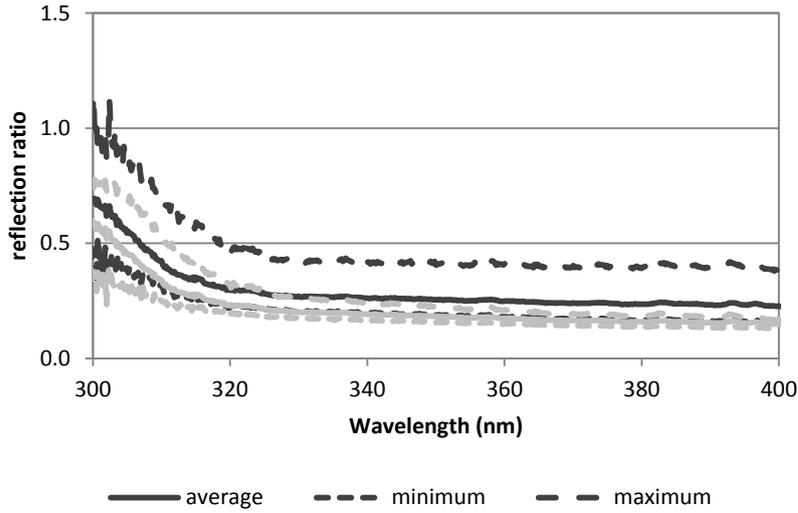


Figure 3 - Reflection measurements from vertical zinc aluminium coated trapezoidal surface from global horizontal UV irradiance measurements (black) and direct normal UV irradiance measurements (grey).

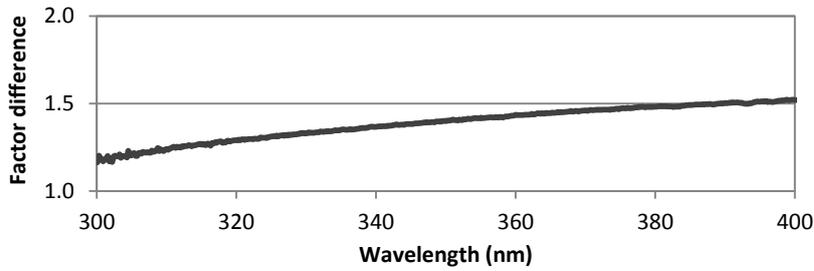


Figure 4 – Factor difference between average reflected global horizontal spectral UV irradiance and average reflected direct normal spectral UV irradiation from a vertical surface.

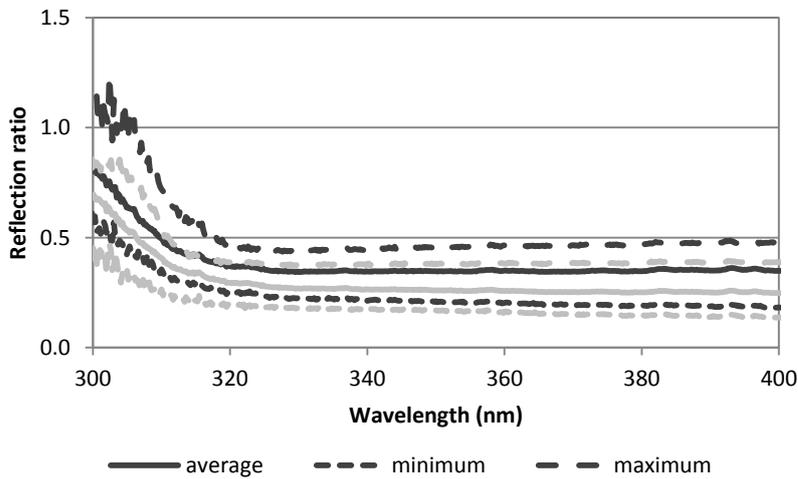


Figure 5 - Reflection measurements from horizontal zinc aluminium coated trapezoidal surface from global horizontal UV irradiance measurements (black) and direct normal UV irradiance measurements (grey).

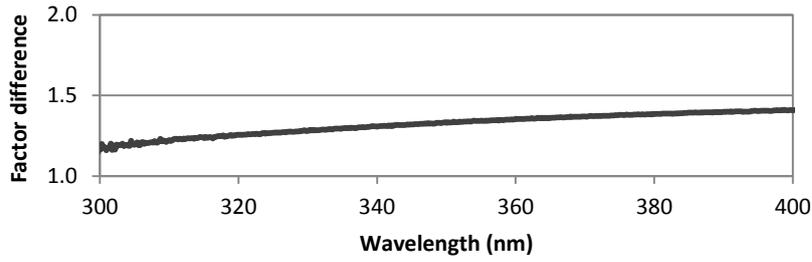


Figure 6 - Factor difference between average reflected global horizontal spectral UV irradiation and average reflected direct normal spectral UV irradiation from a horizontal surface.

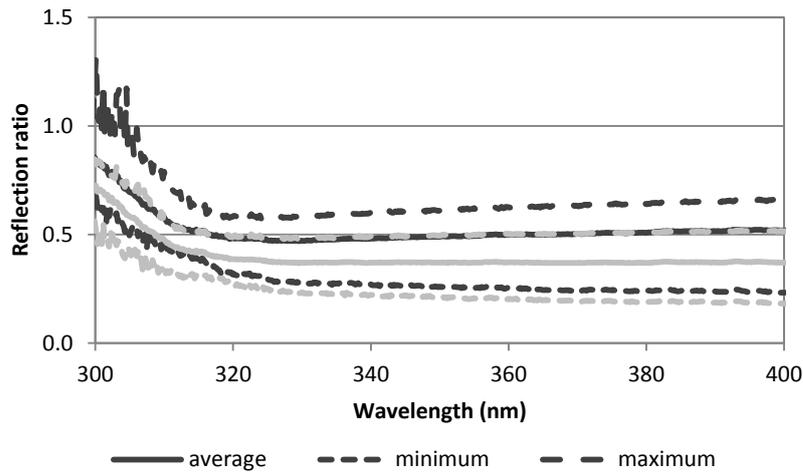


Figure 7 - Reflection measurements from inclined zinc aluminium coated trapezoidal surface from global horizontal UV irradiance measurements (black) and direct normal UV irradiance measurements (grey).

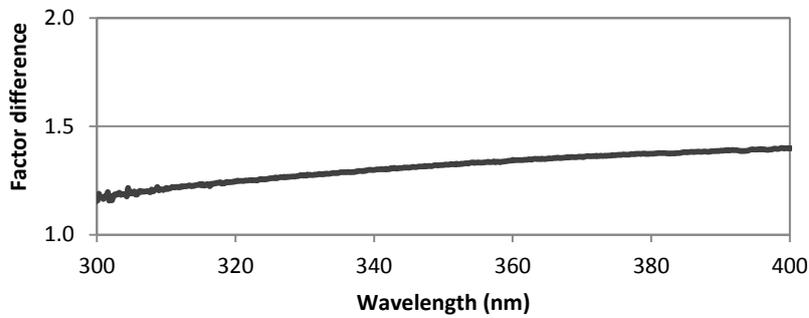


Figure 8 - Factor difference between average reflected global horizontal spectral UV irradiation and average reflected direct normal spectral UV irradiation from an inclined surface.

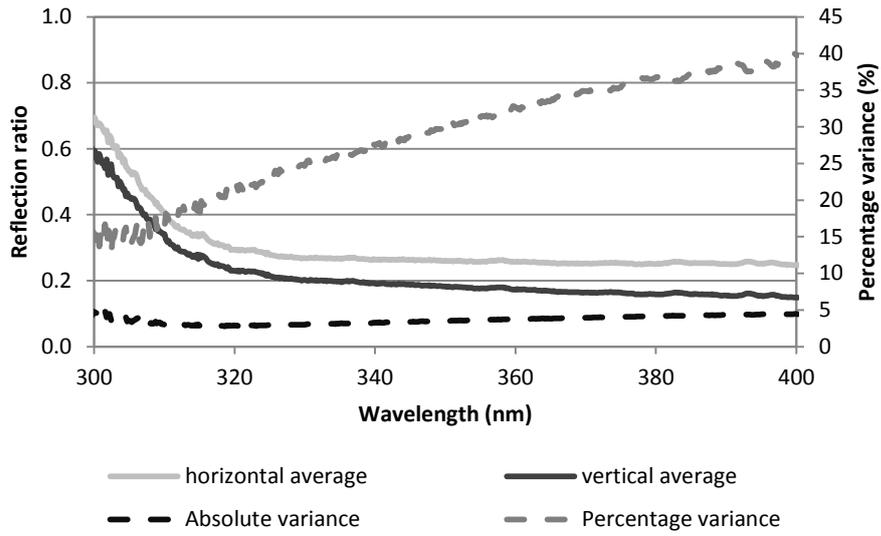


Figure 9 – Comparison of spectral UV direct normal reflection ratio for horizontal and vertical surfaces with absolute and percentage variances.