UVB SURFACE ALBEDO MEASUREMENTS USING BIOMETERS

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ABSTRACT. This work describes ultraviolet-B albedo measurements performed over several surfaces and different atmospheric conditions. These results provide a complement to previous studies as Blumthaler & Ambach (1988), widely used as albedo reference for the main UV radiative transfer models. A custom-built albedometer composed of a pair of Solarlight UVB501 biometer was used to measure the albedo over the following surfaces: green and yellowish grass, sand, wood (natural and painted), formica (synthetic plate), and iron. Influence of clouds and the sensor's response to temperature variations are also discussed. Presence of clouds on surface albedo measurement seems negligible, but a thermo-regulated instrument is indispensable to an accurate analysis. Comparison with previous works shows the need for studies on the detailed characterization of the type of surface.

Keywords: surface albedo, ultraviolet radiation, radiative transfer models.

RESUMO. Este trabalho apresenta medidas de albedo UVB realizadas sobre diferentes tipos de superfície e condições atmosféricas. Tais resultados fornecem uma contribuição a trabalhos prévios, tais como Blumthaler & Ambach (1988) amplamente utilizado em modelos de transferência radiativa. Para tanto, um albedômetro foi construído a partir de dois biômetros Solarlight UVB501 e as medidas foram realizadas sobre as seguintes superfícies: grama verde e amarelada, areia, madeira (natural e pintada), fórmica e metal. Ao contrário de outras publicações sobre o assunto, a influência de nuvens e a resposta do sensor às variações de temperatura foram discutidas com maior profundidade. Verificou-se, que as nuvens não exercem influência significativa sobre a determinação do albedo, enquanto o uso de sensores termo regulados é imprescindível para a obtenção de medidas precisas. Além disso, o trabalho demonstra a necessidade da realização de estudos que detalhem as superfícies estudadas de maneira mais aprofundada.

Palavras-chave: albedo de superfície, radiação ultravioleta, modelos de transferência de radiação.

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INTRODUCTION

Solar ultraviolet radiation that reaches Earth's surface (UV: 280-400 nm) is intrinsically related to the life on our planet. UV radiation exerts influence on aquatics and terrestrial ecosystems and control photochemical and meteorological processes that occurs, mainly, in the stratosphere. This radiation range represents above 8% of the total solar radiation and it is strongly attenuated by the atmospheric elements before reaching the Earth's surface. Solar radiation between 280 and 320 nm, named UVB, bears strong attenuation due to ozone absorption and molecular scattering while passing through the atmosphere. Nevertheless, the small quantity that reaches the Earth's surface is enough to cause several photobiological reactions on human population, animals, and plants, as well as photochemical reactions on inorganic material like plastics and inks. More specifically, human overexposure to UVB is related with adverse health effects, like erythema, sunburn, skin aging, immune suppression and skin cancers. On the other hand, small daily doses are necessary to the vitamin D synthesis in human being (Diffey, 1991).

Theoretical calculations based on radiative transfer models are relevant for studying and evaluating UVB fluxes at the surface. These mathematical tools are of outmost importance in areas where surface instrumentation is scarce or non-existent, a frequent problem due to high costs of UV instruments and their maintenance. This is particularly evident in underdeveloped countries, where skin cancer is also a health public problem (INCA, 2005). In order to calculate accurate UVB fluxes using these computational models, it is necessary to describe the space-time distribution of different atmospheric and surface variables. These variables are:

a) meteorological, such as temperature, wind fields, and cloud coverage;

b) geographical, such as latitude, longitude, and altitude;

c) astronomical, related to the seasonal, and daily sun position; and

d) physical, such as total ozone content and aerosol characteristics (aerosol type, burden and optical depth) and the surface albedo (Diffey, 1991).

The main point of this work is to analyze different surface albedos and propose a brief discussion about the parameters that influence its experimental measurement. This study concentrates the analysis in different patterns of surfaces as wood, formica and steel to provide supplementary information to the known databases. Several UVB albedo studies over usual urban environment surfaces (vegetation, water, concrete, asphalt, sand and snow) were published in recent years:

a) vegetated surfaces (grass): 0.01 and 0.04 (Blumthaler & Ambach, 1988; Feister & Grewe, 1995; Castro et al., 2001);

b) sand: 0.02 to 0.12 (Blumthaler & Ambach, 1988; Feister & Grewe, 1995; Castro et al., 2001; Chadyšienė & Girgždys, 2008);

c) water: 0.05 and 0.08 (Madronich, 1993; Chadyšienė & Girgždys, 2008);

d) concrete: 0.10 to 0.20 (Feister & Grewe, 1995; Castro et al., 2001);

e) asphalt: 0.02 to 0.07 (Castro et al., 2001); and

f) snow: between 0.30 and 0.50 (Doda & Green, 1981; Schwander et al., 1997) and clean fresh snow (up to 90%; Blumthaler & Ambach, 1988).

The reflection is even assumed as isotropic. In such case, the goal of this work is to complement these studies providing new information from different UVB surface albedos for computational model databases.

EXPERIMENT, DATA AND INSTRUMENTATION

The experiment was performed at CPTEC/INPE (Centre for Weather Forecast and Climate Studies / National Institute for Space Research) meteorological station, located in Cachoeira Paulista (22.68°S, 45.00°W, 563.0 m), São Paulo State, Brazil. Data were collected at the end of summer, during two months – March and April, 2005 – under different meteorological conditions such as clear-sky, cloudy, overcast and rainy days. The albedometer system, built from two new and calibrated Solarlight UVB501 biometers (http://www.solarlight.com) is illustrated in Figure 1. The equipment is powered by two 12 V (7 Ah) batteries and a 20 W solar panel. Prior to the albedo measurements, the biometers were intercompared by performing exposition to global solar radiation under clear and cloudy conditions. A set of 7-day measurements was performed, with one-minute resolution. Despite their recent calibrations, the results showed a systematic difference between sensors gain. However, these discrepancies did not show relevant differences under cloudy or not-cloudy conditions or during noon and sunrise/sunset hours. Altogether, measurements indicate a systematic difference of 2.48% in sensor gain. This result allows to using Equation 1, where U_x is the voltage of each instrument, to account for surface albedo correction:
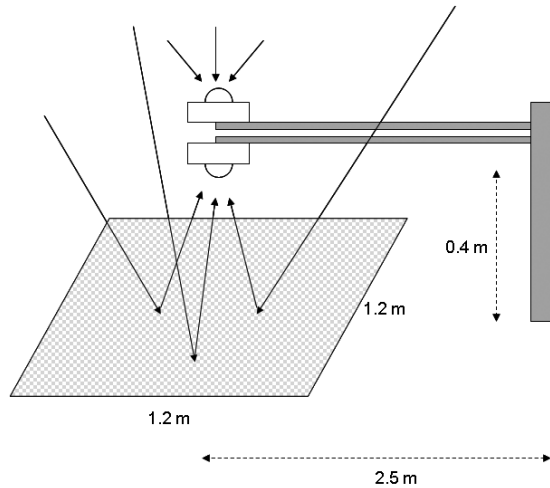
$$U_1 = 1.0248 U_0 \qquad (1)$$

Figure 1 – Albedometer scheme.

Biometers operate according to Robertson-Berger radiometers (Berger, 1976). Solar light penetrates a quartz dome through a black filter that absorbs visible and infrared radiation. Thereafter UV radiation reaches a phosphor sensor that excites and produces radiation detected by a gallium-arsenium-phosphor photodiode (GaAsP). Both elements are built in a thermo-regulated capsule. The photodiode produces electric current that is converted to an amplified voltage through electronic circuits. Finally, voltage is multiplied by the factor calibration resulting in irradiance values. Subsequently, surface albedo (A_{UVB}) is obtained by this relationship:

$$A_{UVB} = \frac{E_u}{E_d} \qquad (2)$$

where E_u is the upwelling irradiance (reflected radiation) and E_d is the downwelling irradiance (global radiation).

According to recommendations proposed by Blumthaler & Ambach (1988; hereafter named BA88), down-looking biometer should be installed between 30 and 50 cm over the ground. In this experiment, the down-looking biometer was installed at 40 cm over the ground. Several measurements were done with instruments placed at 20 and 50 cm, which showed that the differences in the values of albedo were not significant. Below 20 cm, instrument shadow interferes with the measurements. Different surface types were represented in a 1.44 m^2 square plate centered below the albedometer. In this area, albedo of green and yellowish grass, coarse sand (0.2 to 2.0 mm according International classification systems), pinus wood (natural and painted), formica (synthetic plate), and iron surfaces was measured. These different types of surface were chosen as a complement of previous studies as additional information to the numerical models database.

Calibration is only valid below 25°C; thus, internal temperature control is a relevant issue in UV measurement. A Peltier element maintains the inside temperature stable, but due to the high energy consumption the temperature compensation circuit (TCC) is turned off at night, when the radiation level is approximately zero. Sometimes, during overcast or rainy conditions or during sunset or sunrise, the temperature control of the down-looking sensor was automatically turned off even during the daylight. When this artifact happens, measurements can be easily corrected by the following equation:

$$U_{corr} = \frac{U_{meas}}{1 + [T - 25] \times 0.01} \qquad (3)$$

Where U_{corr} is the corrected voltage, U_{meas} is the measured voltage and T is the sensor temperature.

RESULTS AND DISCUSSION

Table 1 shows surface UVB albedo measurements performed in this work. These results have been obtained from averages of minute measurements and correspond to periods of the day when the zenith angle was lower than 70°. For the sake of completeness, the table is complemented by the BA88 results.

Table 1 – UVB albedo results obtained in this work and those published by Blumthaler & Ambach, 1988 (BA88).

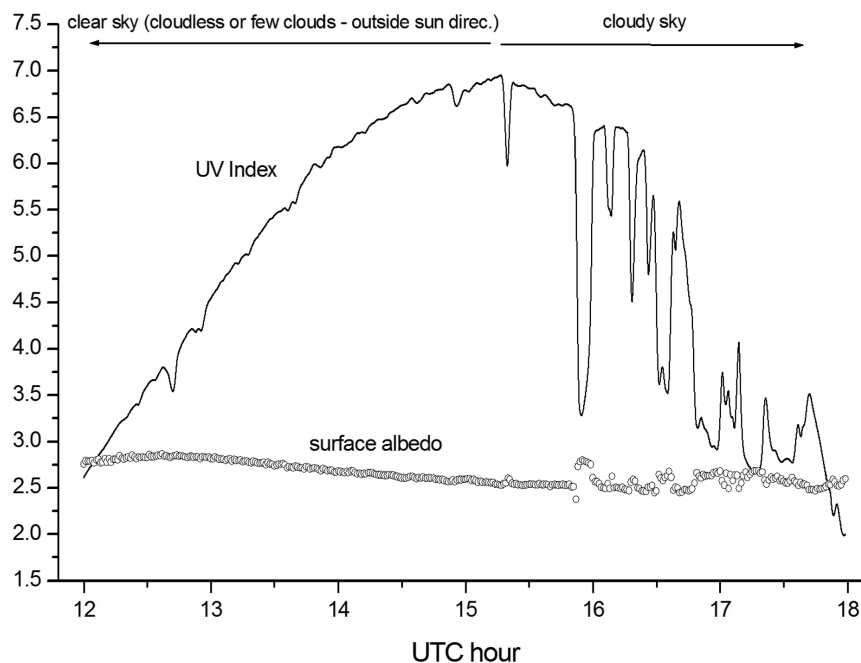| Surface	Albedo (%)	
	This work	BA88
Green grass	1.1 ± 0.1	1.3
Yellow grass	1.0 ± 0.1	–
Stainless steel opaque plate	4.3 ± 0.1	–
Natural clear wood (pinus)	2.6 ± 0.1	–
White painted wood (pinus)	4.2 ± 0.1	–
Black painted wood (pinus)	2.7 ± 0.1	–
White formica (synthetic)	7.9 ± 0.4	–
Wet coarse sand	2.4 ± 0.2	–
Dry coarse sand	4.2 ± 0.1	–
Sand flood	–	9.1
Asphalt	–	5.5
Water	–	4.8
Ice	–	7.8
Soil	–	2.2
Primitive rock	–	3.7
Tennis court	–	2.9
Alpine pasture	–	4.9
Limestone	–	11.2
Dry snow (new)	–	94.4
Wet snow (new)	–	79.2
Dry snow (old)	–	82.2
Wet snow (old)	–	74.4

Figure 2 – UV Index and natural clear wood surface albedo measurements under cloudless and cloudy conditions.

Biometers data were collected during periods of 2-4 days for each type of surface. The different time range allowed evaluating different cloud conditions influence. Figure 2 shows an example of surface albedo (natural clear wood) variations under clear sky and cloudy conditions. During cloudy conditions, observed after noon, instantaneous surface albedo shows slight variations only. Mean surface albedo calculated for 12–15h30 UTC (cloudless) and 15h30–18 UTC (cloudy) shows similar results: 2.7 ± 0.1 and 2.6 ± 0.1 respectively.

The manufacturer (Solarlight Co.) assures a good cosine response for the most part of incidence angles (angular response within 5% from ideal cosine for incident angles smaller than 70°). For this reason, only measurements performed in this interval were used for the mean albedo estimative. Nevertheless, daily variation of surface albedo was also analyzed. Results illustrated in Figures 2 and 3 suggest a slight daily cycle of albedo. Figure 3 makes evident significant albedo variability at sunset and sunrise hours at any surface. These variations can be mainly attributed to the bi-hemispheric reflectance, usually represented by the bi-directional reflectance distribution function (BRDF). BRDF gives the reflectance of a target as a function of illumination geometry and viewing geometry. Discrepancies observed at sunrises and sunsets reinforce this hypothesis. However, a deeper analysis of this phenomenon is out of the scope of this article. Besides, other relevant influences can not be ruled out, such as angle response

sensor, strong fluxes attenuation caused by the longer atmospheric path and the automatic shutdown of the temperature control. Moreover, all measurements performed outside sunset/sunrise hours show very small amplitude (less than 1% between maximal and minimal results) with minimal values at noon. This variation can be attributed to the movement of the sun and the consequent increase of diffuse radiation in periods when optical path is large. In any case, this variation does not represent a significant influence in the mean albedo results.

As described above, Solarlight Co. advises to use the TCC to adjust the temperature sensor close to 25°C. However, TCC is controlled by the radiation flux intensity incident on instrument; the circuit can be turned off in the downward sensor, even during the day, when radiation flux is negligible. In these situations, and also during hotter and colder days, discrepancies can be observed in the measurements. Figure 4 shows a comparison between albedo measured when TCC is turned on and turned off. The internal temperature differences of the instruments are also showed. Results using the applied correction (Eq. 3) show a very good agreement (less than 1%) with results obtained using TCC. In this simulation, when the TCC of the down-looking sensor is turned off the temperature reaches values close to 34°C. In these occasions, the differences observed between the correct and uncorrected albedo results are larger than 10%.
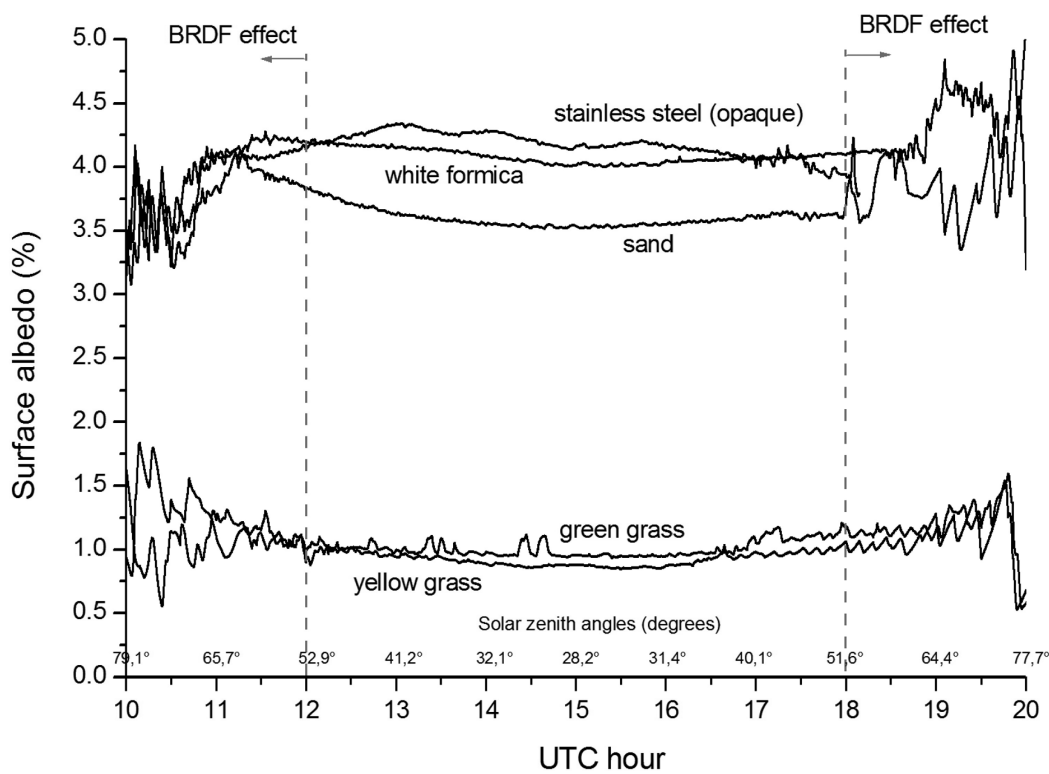
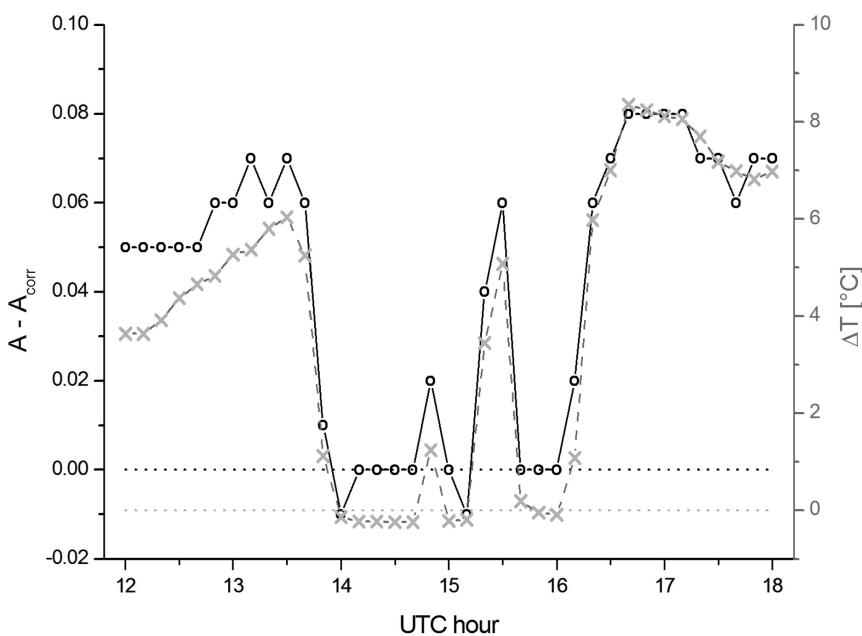**Figure 3** – Daily variations of different surface albedos.

Figure 4 – Temperature compensation circuit influence on albedo results. (Black line: differences between measured albedo without (A) and with (A_{corr}) correction; gray line: differences between core sensor temperature and thermo-regulation temperature (25°C)).

FINAL CONSIDERATIONS

This work shows UVB albedo measurements over different surfaces using an albedometer composed by Solarlight UVB501 biometers. Evaluations of the influence of sensor temperature variations, cloudy-sky conditions and daytime sun-position on albedo measurements were also performed. Despite temperature control ensures accurate measurements, after-measurement corrections using manufacturer equation show acceptable results. However, theoretical or physical temperature correction is always necessary. Cloud cover did not exhibit strong influence on albedo measurements, which shows similar values during cloudless and cloudy conditions. At last, albedo measurements at sunset and sunrise showed meaningful discrepancies possibly attributed to the bi-hemispheric reflectance.

Green and yellowish grass, wet and dry sand, painted and natural wood, black, white, opaque and bright surfaces were analyzed. These accurate measurements provide additional albedo values for radiative transfer models databases for UV Index calculations. Results for green grass (-1.1% $\pm$ 0.1) show good agreement with previous studies (0.8 to 1.1% – Castro et al., 2001; 1.3% – Blumthaler & Ambach, 1988). These small differences may be related to the color or position of leafs. However, relevant differences (2.0 to 20.0%) were observed on sandy surfaces UVB albedo between all of studies (Blumthaler & Ambach, 1988; Feister & Grewe, 1995; Castro et al., 2001; Chadyšienė & Girgždys, 2008). Therefore, studies based on surface properties (e.g., constituents and granulometry of the sand or volume and area leaf for vegetated surfaces) are necessary to evaluate the influences on UVB albedo variations. Besides these comparisons with previous research works, this study provided an incremental database to other materials. It can be very useful for mathematical simulations of UV radiation reflection on tilted surfaces as walls and buildings.

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