Synthesis of vitamin D and erythemal irradiance obtained with a multiband filter radiometer and annual variation analysis in Río Gallegos, Argentina.

P F Orte¹, E A Wolfram², J Salvador²,4, R D'Elia², N Paes Leme³, E J Quel².
¹Fellowship of ANPCyT.
²CEILAP (CITEFA-CONICET) Villa Martelli, Buenos Aires, Argentina.
³Instituto Nacional de Pesquisas Espaciais, Brasil.
⁴Universidad Nacional de la Patagonia Austral, Unidad Academica Río Gallegos, Santa Cruz, Argentina.

E-mail: porte@citefa.gov.ar

Abstract. In this paper we examined the annual variability of the erythemal solar radiation (a health risk) and the solar irradiance for synthesis of vitamin D (a health benefit) in Río Gallegos, Argentina. We use ultraviolet radiation measurements made by a multiband filter radiometer GUV-541 and a Brewer spectrophotometer located at CEILAP-RG Station (CITEFA-CONICET) (51 ° 33' S, 69 ° 19' W). These measurements are weighted with action spectra published by the CIE (International Commission on Illumination). An action spectrum describes the relative effectiveness of different wavelengths in the generation of a particular biological response. The analyzed data correspond to September 2008 - December 2009 period.

The methodology used to obtain the erythemal irradiance and synthesis of vitamin D values combines irradiance measurements of a multiband filter radiometer with modeled values (output of radiative transfer model) and measurements of a Brewer spectrophotometer. This procedure increases the instrumental capabilities of this instrument.

The synthesis of vitamin D and erythema are affected by UVB solar radiation. Therefore, its effect is strongly dependent of the stratospheric ozone amount, which undergoes large variations in the Río Gallegos city due to ozone hole passage and its influence on these sub-polar latitudes.

We observed that could exist cases of sunburn for reasonable exposure in abnormal situations of low total ozone column, resulting in high levels of ultraviolet radiation. Furthermore, the synthesis of vitamin D through exposure to ultraviolet radiation would be lower than the appropriate values to the majority of the year for these latitudes. Therefore it is important to evaluate the annual variation of these quantities realizing seasonal balance between this health risk and this health benefit.

1. Introduction

Excessive exposure to UV radiation can cause a range of adverse health effects, such as sunburn, ocular damage, suppression of the immune system, and induction of skin cancers [1]. On the other hand, this radiation can benefit the human health. One of the most important benefits is the synthesis of vitamin D (photoconversion of precursors such as dehydrocholesterol in previtamin D). Vitamin D deficiency causes a inadequate intestinal absorption of calcium, leading to decreased blood. This calcium decrease is compensated at the expense of bone calcium. It can result in a bone density decrease and lead to problems of rickets in children. In addition, there is
strong evidence that solar UVB irradiance, through production of vitamin D, reduces the risk of cancer [2]. Generally, our dietary intake of vitamin D is far below the level required to maintain optimal levels of blood serum vitamin 25(OH)D, so some UV exposure is desirable to maintain healthy vitamin D levels[3].

For people living at higher latitudes where the solar UV radiation is too weak during winter for the synthesis to take place, it is of great importance to obtain adequate vitamin D through diet (food or supplement) to avoid vitamin D insufficiency [4]. For example, previous studies made in Ushuaia, Argentina (54° 50’ S, 68° 18’ W) have shown that the radiation in surface is not sufficient to synthesize appropriate vitamin D levels and supplementation of this vitamin was recommended in children. [5].

The potential of harmful UV radiation is commonly reported in units of Global UV Index (UVI) [6]. The unit is based on the CIE erythema (sunburn) action spectrum [7] and has been internationally adopted for reporting measured and forecasted erythemally effective UV irradiance. In the same way, we can calculate the vitamin D-weighted UV (UV_{VitD}) based in the appropriate CIE action spectrum to this end. UVI and UV_{VitD} may be retrieved directly from spectral measurements with a high resolution spectroradiometer. For radiometers with wider bandwidths and a limited number of detector channels, such as multiband filter radiometers (MBFRs), deriving UVI and UV_{VitD} is more challenging, as it requires a conversion function and absolute calibration through a high-resolution spectroradiometer. Dahlback [8] and Bernhard et al. [9] have shown that measurements from MBFRs may be converted to UVI as a weighted sum of output from discrete detector channels in the UV. The method forms a basis for reporting UVI from MBFRs operating in UV-monitoring networks.

This paper is based on the methodology used by Dahlback in order to obtain the biologically Effective UV dose with a multiband filter radiometer and obtain the UV_{VitD} in Río Gallegos, Argentina, between UV spectroradiometer very expensive and high maintenance, and broadband radiometers that provide only partial information because they cannot distinguish between changes in UV radiation caused by alterations in cloud cover and variations caused by changes in ozone amount. The GUV-541 has five UV measurement channels with central wavelengths at 305, 313, 320, 340 and 380 nm and a bandwidth of FWHM=10 nm approximately. This instrument integrates the Solar Monitoring Network Argentina (http://www.dna.uba.ar) and is part of the passive sensing station CEILAP in Río Gallegos, Santa Cruz, Argentina.

The Brewer Spectrophotometer MKIV is a scientific instrument which measures Ultra Violet radiation in the solar spectrum. The Brewer spectroradiometer MKIV has a monochromator that operate with a holographic diffraction grating and permit the UV solar irradiance measurements in the 290 nm to 325 nm range with a wavelength resolution of 0.5nm. This instrument invests three minutes to measure a complete spectrum.

Through mercury and halogen internals lamps the spectroradiometer Brewer make some automatically daily calibration test through of “standard lamp test”. This test is a general quality-assurance examination of Brewer performance across the full range of operational wavelengths. An internal, well-regulated, quartz-halogen 'standard' lamp is used as the light source. This source produces a continuous light spectrum (unlike the mercury lamp which emits discrete wavelengths) which is stable and consistently reproducible.

To determine the UV dose rate, labeled D instead of dD/dt for simplicity, from a spectroradiometer, we need to convolve the spectral irradiance F(λ) with a biological action spectrum A(λ):
where $\Delta \lambda$ is determined by the resolution of the spectroradiometer. The UV dose is a time-integrated quantity and is obtained when we integrate the UV dose rate over a specified time interval. A multichannel filter instrument, however, has only a few channels $M$ available in the UV part of the spectrum. Now we attempt to determine the UV dose rate by a linear combination of the irradiances (represented by the voltages $V_i$) measured by the $M$ channels. For a filter instrument having $M$ channels,

$$D_{\text{approx}} = \sum_{i=1}^{M} a_i V_i$$  \hspace{1cm} (2)$$

The goal is to determine a unique set of these $M$ coefficients $a_i$'s. Thus we try to determine accurate dose rates for a specified action spectrum for all realistic atmospheric conditions (primarily variable ozone amount, ozone profile, solar zenith angle, cloud cover, and surface albedo) by using one single set of $a_i$'s in Eq. (1). We proceed by requiring that the accurate expression for the dose rate Eq. (2), $D_{\text{exact}}=D_{\text{approx}}$.

$$\sum_{i=1}^{M} a_i V_i = \sum_{\lambda=0}^{\infty} A_{\lambda} F_{\lambda} \Delta \lambda$$  \hspace{1cm} (3)$$

We need a set of $M$ equations to obtain a solution of the $M$ unknowns $a_i$'s. This was obtained by simultaneous measurements with a spectroradiometer and the filter instrument at $M$ different solar conditions.

If $A(\lambda)$ is the CIE erythemal action spectrum for Caucasian skin type or the action spectrum for vitamin D, we can obtain the erythemal weighted UV ($UV_{\text{Ery}}$ in W/m^2 or UV index, $I_{UV}=40xUV_{\text{Ery}}$) and the vitamin D-weighted UV respectively.

With five channels in the MBFR we need five different spectra to solve for the five $a_i$'s in Eq.(3).

To calculate the UVI from the GUV-541 MBFR with the described method, the five spectrums $F_{\lambda}$ in Eq.(3) were modeled to obtain the coefficients $a_i$'s with radiative transfer model UVSPEC/libRadtran-1.3[10]. The wavelength resolution selected to these spectrums was 1nm. These spectrums were modeled to different solar zenith angles (SZA) and different ozone amounts ( 35°-250 DU; 35°-400 DU; 70°- 250 DU; 70°-400 DU; 52.5°- 325 DU).

To calculate the vitamin D-weighted UV ($D_{\text{exact}}$ in Eq. 1) we tried to obtain the coefficients $a_i$'s similarly to the UVI method using the spectroradiometer brewer and the model, but the result were not goods. Therefore, to obtain the better coefficient group to calculate the UV$_{\text{VitD}}$ from the GUV instrument, we selected 65 solar spectrums to clear sky situation measured from the spectroradiometer Brewer ($F(\lambda)$) to a year period. With this 65 spectrums we generate 65 equations like the Eq.(3) between the Brewer spectroradiometer and GUV-541 channels, with a temporal difference between the start of the spectral measurement taken by the spectroradiometer and the GUV measurements less than 20 seconds. The ozone amount range to obtain the coefficient was 270 – 430UD and the SZA range was 30 – 70°. The weighted function for vitamin D is zero to wavelength bigger than 330nm. Therefore, when we calculate the vitamin D-weighted UV, the cannel of 340nm and 380nm are equal to zero, so we need three equations to solve this equation system to obtain the three coefficients to the channels centred in 305nm, 313nm and 320nm.

With the 65 equations mentioned to clear sky conditions, we generated systems of 3 equations with 3 unknowns factors ($a_i$'s) combining all equations to obtain the $a_i$'s coefficients that solve each equations system and determine what coefficient group are more repeated. Finally, with this coefficients group we obtain the UV$_{\text{VitD}}$ [W/m^2] from GUV-541 MBFR and these results were compared with obtained from the Brewer spectroradiometer.
3. Results and discussion

The coefficients obtained through the method described to obtain the vitamin D-weighted UV are:

\[ a_1 = 0.11915, \quad a_2 = -0.05808, \quad a_3 = 0.02906, \]

which \( a_1, a_2 \) y \( a_3 \) are the coefficients to the GUV channels centred in 305nm, 313nm y 320nm respectively.

\[ \text{y}(x) = a + b \times x \]
\[ a = -5 \times 10^{-6} \]
\[ b = 1 \]
\[ R = 0.998 \]

**Figura 1.** Correlation of vitamin D-weighted UV obtained by GUV and Brewer spectroradiometer in clear sky conditions.

The Figure 1 show a scatter plot of the UV\(_{\text{VitD}}\) obtained to Brewer spectroradiometer and MBFR GUV-541 to clear sky situation from November 2008 to December 2009. We can observe a very good correlation whit a coefficient R near to 1. This result validates the developed method.

The relative difference between both instruments (Figure 2) in the vitamin D-weighted UV is less than 5\% for SZA lesser than 45\(^\circ\), and is less than 10\% for SZA’s lesser than 65\(^\circ\). This is a good result considering that these instruments are independent.
Figure 2. Relative difference of vitamin D-weighted UV obtained by GUV-541 respect to Brewer spectroradiometer to clear sky condition.

The Figure 3 show a scatter plot of the UV_{VitD} obtain to spectroradiometer Brewer and GUV-541 MBFR but to all sky conditions from November 2008 to December 2009. The time difference between each pair of data is less than one minute. We observe a good correlation between both instruments but we can see a big dispersion introduced by clouds and this derive in a large relative difference. This difference may be due to independent instruments respond differently when the cloud optical thickness varies. It can also be associated with the time difference between the GUV and the measurement of the Brewer spectroradiometer. Furthermore, the Brewer invests three minutes to obtain a spectrum while the GUV-541 has a minute temporal resolution.

Figure 3. Correlation of vitamin D-weighted UV obtained by GUV and Brewer spectroradiometer in all sky condition.

Vitamin D-weighted UV annual variability.
The Figure 4 shows the annual variability of daily UV_{VitD} dose (triangles) from the November 2008 to December 2009. In order to establish if there is synthesis of vitamin D in Río Gallegos during the study period is necessary to compare these values of UV_{VitD} dose with a threshold value.

While there is considerable uncertainty regarding the wavelength dependence for vitamin D production, evidence suggests that there is insufficient vitamin D produced in the winter at latitudes pole-ward of about 40° [11]. McKenzie et al. based on the statement that no vitamin D is
produced in the winter at Boston, MA, take an upper limit threshold for insufficient vitamin D production as the daily available dose at the latitude of Boston, 42°N. This threshold is about 0.7 KJ/m2 per day.

![Graph showing vitamin D-weighted UV dose](image)

**Figure 4.** Annual variability of daily vitamin D-weighted UV dose (triangles) from the November 2008 to December 2009 obtained by GUV-541.

We adopt this threshold as a value that must be overcome so that a person can synthesize sufficient vitamin D (grey line). Therefore, we can observe in figure 4 that a person in Río Gallegos could start to synthesize vitamin D from the sun beginning of spring, with a maximum synthesizes at the end of spring and early summer. Then, in late summer, the synthesis of vitamin D stops. During the autumn and winter do not exist vitamin D synthesis practically.

**UV Index annual variability.**

If we analyze the annual variability UV Index obtains from GUV-541 by J. Salvador using the Dahlback method (Figure 5), we can see some high UVI values which they could cause erythema to reasonable exposure periods. To exemplify we can observe the dashed line indicate UVI=10. If a person whit skin type II is exposed to this index, will induces erythema in a period of 20 minutes [3]. As a consequence, the days when the maximum UVI exceed this line, a person could induce erythema to less than 20 minutes in Río Gallegos in spite of the high latitude.

![Graph showing UV Index variability](image)

**Figure 5.** Annual variability UV Index obtained by GUV-541 from the November 2008 to December 2009.
On the other hand, we can observe abnormal high values of UVI due to the ozone hole and its edge passing over RG. Some of these cases are presented in the Figure 5 (6, 21 and 29 October 2008 and 15 November 2009 with daily mean ozone amount of 275 DU, 232 UD, 261 DU and 241 DU respectively).

Therefore, we observed that also could exist sunburn cases for reasonable exposure in abnormal situations of low total ozone column due to ozone hole passing over Río Gallegos.

4. Conclusions

In this work we achieved to obtain the vitamin D-weighted UV to Río Gallegos, Santa Cruz, Argentina, from GUV-541 multiband filter radiometer using a Brewer spectroradiometer through of Dahlback method. The relative difference between these instruments was less than 10% for SZA less than 65º to different ozone amounts (from 270 to 430 DU) in clear sky conditions.

For cloudy sky situations the relative difference between the measurements of mentioned instruments was not good, but exist correlation between both instruments. We are study the cloudy sky conditions cases to reduce the large relative difference in the vitamin D-weighted UV obtained for MBFR. One solution could be obtaining some “error function” related with the cloud optical thickness.

Analyzing the vitamin D weighted dose synthesized through solar UV radiation we note that this value is insufficient during five or six month of year in autumn and winter. The vitamin-D weighted synthesized dose through the sun is a problem to people who lives in similar latitudes to RG or larger.

On the other hand, when we analyze the UVI, we can observe that there are special cases of UVI higher than normal situation due to the passage of the ozone hole and its edge over Río Gallegos. In these cases and in a few days of spring and summer, the radiation UV may reach high values and result in erythema for reasonable exposure times.

These conclusions are subject to exposure limits adopted, since there is high uncertainty mainly related studies at the recommended dose to synthesize vitamin D.

5. References

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