An alternative method for calibration of narrow band radiometer using a radiative transfer model

J. Salvador1,4, E. Wolfram1, R. D’Elia1, F. Zamorano2, C. Casiccia3, A. Rosales3 and E. Quel4

E-mail: jsalvador@citefa.gov.ar

1 Centro de Investigaciones en Láseres y Aplicaciones, CEILAP (CITEFA-CONICET), Juan B. de La Salle 4397 (B1603ALO), Villa Martelli, Buenos Aires, Argentina.
2 Laboratorio de Ozono y Radiación UV, Universidad de Magallanes, Punta Arenas (Chile)
3 Universidad Nacional de la Patagonia San Juan Bosco, UNPSJB, Facultad de Ingeniería, Trelew (Argentina)
4 Universidad Nacional de la Patagonia Austral, Unidad Academica Rio Gallegos Avda. Lisandro de la Torre 1070 ciudad de Rio Gallegos-Sta Cruz (Argentina)

Abstract. The continual monitoring of solar UV radiation is one of the major objectives proposed by many atmosphere research groups. The purpose of this task is to determine the status and degree of progress over time of the anthropogenic composition perturbation of the atmosphere. Such changes affect the intensity of the UV solar radiation transmitted through the atmosphere that then interacts with living organisms and all materials, causing serious consequences in terms of human health and durability of materials that interact with this radiation. One of the many challenges that need to be faced to perform these measurements correctly is the maintenance of periodic calibrations of these instruments. Otherwise, damage caused by the UV radiation received will render any one calibration useless after the passage of some time. This requirement makes the usage of these instruments unattractive, and the lack of frequent calibration may lead to the loss of large amounts of acquired data.

Motivated by this need to maintain calibration or, at least, know the degree of stability of instrumental behavior, we have developed a calibration methodology that uses the potential of radiative transfer models to model solar radiation with 5% accuracy or better relative to actual conditions. Voltage values in each radiometer channel involved in the calibration process are carefully selected from clear sky data. Thus, tables are constructed with voltage values corresponding to various atmospheric conditions for a given solar zenith angle. Then we model with a radiative transfer model using the same conditions as for the measurements to assemble sets of values for each zenith angle. The ratio of each group (measured and modeled) allows us to calculate the calibration coefficient value as a function of zenith angle as well as the cosine response presented by the radiometer. The calibration results obtained by this method were compared with those obtained with a Brewer MKIII SN 80 located in the city of Punta Arenas, Chile using the sun as a source. These results show us that the proposed method is a viable alternative for developing countries that use instrumentation of this type and find it difficult to apply calibration programs on a regular basis.

Keyword: Radiometer, UV, Calibration.

1. Introduction
The moderate bandwidth radiometers (between 1 and 12 nm) frequently used in remote sensing studies are routinely calibrated using the method of exposure and contrast with optical standards based on incandescent lamps. These radiometers are generally used to measure solar irradiances that have spectral distributions that differ significantly from the spectrum of calibration lamps used by the manufacturer. When these instruments are applied to spectral regions where the solar spectrum has large variations in intensity such as the UV region, for example,
measurement errors of more than 75% in the 305 nm channel may occur when compared with those measured made by a spectrometer having high resolution [1].

In an attempt to avoid these differences, Biospherical Instruments implements a calibration which combines solar calibration and lamps [2], which are made through direct comparison with measurements made with a spectroradiometer (SUV-100) with a bandwidth of 1 nm. This standardized procedure for comparison with lamps produces good results if the channels are calibrated in wavelengths greater than 320 nm, but there are some problems for wavelengths shorter than this value, because the solar spectrum is radically different than the spectrum of the calibration lamp.

One of the common problems that occur with the maintenance and monitoring of the stability of these instruments in developing countries is that it is not readily possible to return the instrument to the manufacturer or to make intercomparisons with a patron radiometer because both procedures are very expensive. This is the fundamental motivation of this paper in which we describe the use of a radiative transfer model to obtain an alternative method of calibration that also succeeds in monitoring the temporal stability of these instruments.

2. Methodology of applying a radiative transfer model

In this paper, the instrument used for measurements of ultraviolet radiation is a moderate narrow band radiometer with filters, called GUV-541 that is manufactured by the company Biospherical Instruments Inc, San Diego. The optical part of such instruments typically consists of a Teflon or quartz diffuser, interference filters and detectors sensitive to light. The GUV-541 has five UV measurement channels with central wavelengths at 305, 313, 320, 340 and 380 nm. Each channel has 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 remote sensing station of CEILAP in Rio Gallegos (51° 55’S,69° 14’W), Santa Cruz-Argentina www.division-lidar.com.ar.

The methodology used in this study to calibrate or convert voltages to values of spectral irradiance is as follows: comparison of the voltage measured by the instrument in the five channels with the irradiances modeled using a radiative transfer model called libRadtran. This model has a routine called UVSpec that calculates the spectral irradiances for the visible and UV region. The solution to the radiative transfer equation is conducted by the DISORT2 computer code. Further information is given by the web source http://www.libradtran.org [3]. The application of the method is as follows. First, it is necessary to select a set of clear days separated over a period of three to five months, generally around the summer. From these days are chosen sets of values corresponding to the same zenith angle but mixing different days.

In the present study we consider twelve zenith angles between 30 ° and 85 ° at 5 ° intervals. This ensures that the modeling of the atmosphere is represented by the average conditions of the model input parameters, such as surface albedo and aerosol content, which will be the same for all calculations. The modeling is then performed for each zenith angle, with the value of ozone for the same day, taken from the OMI instrument aboard AURA satellite for Rio Gallegos. The modeled spectra are weighted by using the response filters provided by Biospherical Instrument Inc of FWHM 10 nm centered in the wavelength of each channel for channels higher than 320 nm.

The filter response curves were measured by the manufacturer using a setup which consisted of the illumination of the sensor with light at a wavelength that is less than the spectral filter response (typically 1 nm is used). Then a scan in wavelengths is conducted on the sensor where each value voltage in the output of the sensor is stored at specific wavelength used as input into the model. The procedure followed is to obtain for each zenith angle n values of voltages provided by the sensor and n values determined by the model calculated for the same zenith angle, with n equal to the number of study days. The calibration factors (CF) for each channel is calculated as the ratio between the channel voltage and the irradiance value obtained by the radiative transfer model. The calibration factor is a function of zenith angle, see Equation (1).
\[ CF_{channel}(\theta) = \frac{V_{channel}(\text{volts}) - V_{offset}(\text{volts})}{\int_{0}^{\infty} R_{Di}(\lambda) E(\lambda) d\lambda} \left[ \frac{\text{volts}}{\mu W / (cm^2 \cdot nm)} \right] \] (1)

Where:
- \( R_{Di} \): Represents the standardized response filter for the channel i of the radiometer.
- \( E \): Spectral emission provided by the radiative transfer model between 280 and 400 nm.
- \( V_{channel} \): Values voltages from the radiometer, these values provide the irradiance values relative to the noise as a scaled values of voltage.
- \( V_{offset} \): Noise voltage in each channel, in this paper these values are determined by using the night values recorded in the period typically between 20 pm to 3 am UTC time.

### 2.1. Results and discussion

In this paper we will evaluate two different ways for getting the calibration coefficient. One mode is use a Gaussian distribution for the quantity \( R_{Di} \). The other way is use the real response filter of the instrument that in this case was provided by the manufacturer. In our case, as the first step we will evaluate the calibration coefficient using as filter response a Gaussian distribution with FWHM of 10 nm.

Figure 1 present plots of the calibration factors (CF) against zenith angle. Due the latitude of Río Gallegos, the solar maximum elevation is around 70º, and for this reason values for zenith angles less than 30º are not considered in these calculations. The variability of CF with the relative position of the sun is obvious for the channels in the UVB region, especially at the wavelength of 305 nm. This result is in agreement with the errors reported for this type of instrument in different weather conditions.

![Figure 1. Calibration Factors (CF) for each channel of the GUV 541 depending on the zenith angle, evaluated with a filter with Gaussian distribution FWHM=10 nm.](image)

Table I lists the values of the original calibration factors (CF_Bios), provided by Biospherical Instruments Inc in the 2005 year which was the last calibration by the manufacturer (Table I, second column). The calibration factors are compared with CF_Mod values calculated using the method proposed. These values are calculated as the average of the CF for all zenith angles studied. The relative error between the original CF_Bios and CF_Mod calculated by this method increased for the channels with shorter wavelengths, confirming that there is a minor discrepancy between the value of CF_Bios and the CF_Mod obtained with the proposed method in the UVA. The relative error increases to a maximum of 79% for the 305 nm channel.
A better estimate of the calibration coefficient together with the radiative transfer model is performed using the real spectral response of each filter provided by the manufacturer. In Figure 2, the filters are displayed in five channels or wavelengths. It should be noted that the filter response for the 305 nm, the cutoff of the filter is only for those wavelengths greater than 305 nm, while the cutoff in the lowest wavelengths is given by the atmosphere. So it possible to see (Figure 2) that the FWHM in the channel 305 nm is greater than the other channels

![Figure 2](image.png)

**Figure 2.** Response filters for each channels from GUV-541 provided by Biospherical Instrument Inc. San Diego

We see in Table II the comparison, between the calibration factor provided by Biospherical Instruments Inc, and the new calibration factor calculated using the methodology proposed. In general all the relative differences obtained in this case are less than the values obtained in the previous case, but still the differences are increasing in the UVB region (305 and 313 nm channels). The errors for the other channels that are within the UVA region present a good agreement and its error is about 7%.

**Table I.** Second column represent the calibration coefficient provided by Biospherical Instrument Inc in 2005 year. The third column represent the calibration coefficient calculated by the method. Fourth column are derived the relative error between both methodologies.

| Channels | Calibration Factor Biospherical Volts/ (μW/(cm².nm)) | Calibration Factor Method Volts/ (μW/(cm².nm)) | Relative error (CFBiospherical-CFmethod)/CFmethod |
|----------|-----------------------------------------------------|------------------------------------------------|-------------------------------------------------|
| 305      | 0.2973                                              | 0.1655                                          | 79.6%                                           |
| 313      | -0.2558                                             | -0.2374                                        | 7.7%                                            |
| 320      | -0.1324                                             | -0.1231                                        | 7.5%                                            |
| 340      | -0.0811                                             | -0.0785                                        | 3.3%                                            |
| 380      | -0.0505                                             | -0.0525                                        | -3.8%                                           |
Table II. Calibration coefficient in third column calculated with the use the response filters obtained by the Biospherical Instruments Inc. The relative error between both methods are shown in fourth column.

| Channels | Calibration Factor Biospherical Volt/ (μW/(cm².nm)) | Calibration Factor calculated by libRadtran-1.3 [V/(μW/(cm².nm))] | Relative error (CFBiospherical-CFmethod)/CFmethod |
|----------|---------------------------------------------------|------------------------------------------------------------------|-----------------------------------------------|
| 305      | 0.2973                                            | 0.25859                                                          | 14.97%                                        |
| 313      | -0.2558                                           | -0.21543                                                         | 18.74%                                        |
| 320      | -0.1324                                           | -0.13555                                                         | -2.32%                                        |
| 340      | -0.0811                                           | -0.083496                                                        | -2.87                                         |
| 380      | -0.0505                                           | -0.05459                                                         | -7.49%                                        |

3. Solar calibration

To test the feasibility of the calibration method proposed by the use of radiative transfer model, we made a solar calibration for both a GUV radiometer and a Brewer spectrophotometer. The period from February 19 - 25, 2008 was used for this calibration procedure of a GUV-541 radiometer (property of CEILAP) was conducted in the laboratory Ozone and Ultraviolet Radiation of UMAG (University of Magallanes) located in the city of Punta Arenas (53.03 S, 70.85 W) - Chile. For the calibration procedure, the radiometer GUV-541 together with a Brewer SN 180, model MKIII, were located on the roof of laboratory to see the direct sun. The procedure of solar calibration is a method that basically allows a calibrated instrument such as the Brewer obtain solar spectras at regular intervals that can then be compared with the voltage values measured by the radiometer GUV-541 at the same time. Using a simple regression it is possible to obtain the calibration factor for each channel. Table III summarizes the study days for this analysis.

| Study Days | UTC Time |
|------------|----------|
| 19/02/2008 | 16:32    |
| 20/02/2008 | 00:00    |
| 22/02/2008 | 13:05    |
| 23/02/2008 | 00:00    |
| 24/02/2008 | 00:00    |
| 25/02/2008 | 00:00    |

Table III. Days of analysis used in the calibration process calibration in Punta Arenas-Chile. The UTC time represent the start of the measurement.

3.1. Results and discussion

Figure 4 displays the four calibration curves implemented through a scatter plot. The Y axis represent the voltage GUV-541 radiometer, and the X axis is the solar spectral irradiance value obtained from the Brewer MKIII, centered on the wavelength of the each radiometer channel. A liner regression fitting is made to obtain the calibration factors. One important note is that the GUV-541 radiometer has five different channels. Due to the upper limit of spectral range of this Brewer (363 nm), we can only derive the calibration coefficient of four GUV channels, separating the channel 380 nm from this methodology.
Figure 4. Calibration curves obtained by a combination of Brewer and voltages values from the radiometer GUV-541. A lineal regression is applied to obtain the calibration coefficient.

Table IV shows the numeric result of the scatter plot in (Figure 4), the second column we have the calibration coefficients supplied by the Biospherical Instruments Inc. In the third column we present the calibration coefficients calculated from linear regression from Figure 4. In column four, the relative errors between the Biospherical Instruments Inc and the solar calibration implemented in Punta Arenas on February 2008, are listed.

| Channels | Calibration Factor Biospherical [Volt/ (μW/(cm².nm))] | Calibration Factor (Solar Calibration)[CF_solar] [V/(μW/(cm².nm)))] | Relative error % (CF_Bios-CF_solar)/CF_solar |
|----------|-----------------------------------------------------|-------------------------------------------------|-----------------------------------------------|
| 305      | 0.2973                                              | 0.25635                                         | 15.97%                                        |
| 313      | -0.2558                                             | -0.25152                                        | 1.70%                                         |
| 320      | -0.1324                                             | -0.12922                                        | 2.46%                                         |
| 340      | -0.0811                                             | -0.071738                                       | 13.05%                                        |
| 380      | -0.0505                                             | NaN                                             | NaN                                           |

Table IV. Comparison between different calibration coefficient obtained by the company Biospherical Inc in 2005 year, and the solar calibration implemented in Punta Arenas on February 2008.
4. Conclusions

An alternative method of calibration for narrow band radiometer is proposed, developed and compared with the solar calibration method. The methodology proposed uses a radiative transfer model called libRadtran version 1.3 and the use of an algorithm for selection of clear skies allowing to determine the calibration coefficients for the multichannel radiometer GUV-541 of Biospherical Instrument Inc.

The instrument was calibrated for the last time by Biospherical in 2005. We can see also that the use of synthetic Gaussian filters with FWHM = 10 nm show good agreement for the calculation of calibration coefficients (TABLE I), except for the 305 nm channel, where the relative error is increased to about 80%. Using response filters characterized by the manufacturer especially for the channel of 305 nm, the new methodologies allowed the determination of the calibration coefficients with a relative error of 7% for the channels within the UVA region (320,340,380 nm). The relative error is two-fold higher for the two channels within the UVB region (305, 313 nm), around 15% compared always with the original coefficients. A second method, using solar calibration, compared the radiometer GUV-541 with a Brewer MKIII SN 180 of the UMAP Punta Arenas, Chile, and these results allowed the determination with a linear regression the calibration coefficients, which show a similar trend in terms of increases relative error for UVB channels, particularly in the 305 nm channel. This paper concludes that both methods have similar errors for channels 320 and 340 nm and that the stability over time is good. For the 305 nm channel both methods give a calibration value with a relative difference less than 1% but with differences of 15% compared with the original calibration coefficient made by Biospherical Instruments Inc in 2005, which can determine that the channel must be corrected. Finally this proposed method does not try to replace the traditional methods of calibration, but could be considered as a useful tool for those groups or laboratories that do not have the enough resources to test calibration and stability of their instrument with time.

6. References

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