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Temperature effects correction in a Brewer MKIV spectrophotometer for solar UV measurements

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Abstract. The increasing demand for accuracy in the measurement of the solar UV-spectral irradiance, has motivated an investigation of the dependence of the spectral responsivity of our Brewer MKIV spectrophotometer on the ambient temperature. The study has been performed using a set of 50 W tungsten-halogen lamps whose specific intensities have been calibrated by a National Institute of Standards and Technology referenced lamp. The main observed feature is a decrease of the responsivity of the instrument with increasing temperature: this effect is greater at low wavelengths and can produce mean inaccuracies over the 290–325 nm spectral interval ranging from 2% in the cold season up to 8% in summer. The proposed correction methodology makes use of a family of responsivity files (uvres files) made at different temperatures and normalized to a calibration performed with a referenced lamp at a given temperature. Each UV spectrum taken along the day will be calculated using the uvres files corresponding to the same temperature at which the spectrum has been measured. The appropriate uvres will be obtained by linear interpolation of the already determined responsivity files.

1. Introduction

The improvement of the accuracy of ground-based spectrophotometers in measuring the spectral solar UV-B irradiation is of paramount importance both in connection with the observed stratospheric ozone decrease and in providing reliable "truth" values for UV model calculations and for validation of the data retrieved from satellite measurements.

One of the most used spectrophotometers is the single monochromator Brewer instrument (MKII and MKIV) and, more recently, the double monochromator version (MKIII). The Brewer is an optical instrument designed to measure ground level intensities of the attenuated incident solar ultraviolet radiation at five specific wavelengths in the absorption spectra of ozone and sulfur dioxide. The ozone total column content is obtained from a combination of the solar irradiance from four wavelengths. The MKIV version allows switching to nitrogen dioxide operation at 430–450 nm: it contains a modified Ebert f/6 monochromator with a 1200 line/mm holographic diffraction grating, operated in the third order for ozone and sulfur dioxide and second order for nitrogen dioxide; used in the UV mode, it measures the solar spectrum from 290 to 325 nm [*Brewer*, 1973; *Kerr et al.*, 1980, 1984]. The Brewer instrument can be operated automatically outdoors using a sun-moonlight tracking system and predetermined schedules. A Brewer network is in operation all over the world and is mainly devoted to measuring the ozone column and the solar UV-B (and UV-A) radiation. The Brewer appears quite stable with respect to ambient temperature variations and is not provided with a temperature stabilized enclosure as required by other spectrophotometers when used outdoors. However, temperature effects on the single-monochromator Brewer responsivity have already been observed [*Bais et al.*, 1995] with variations of some percent for temperature gradients of 15°–20°C (*K. Lamb*, private communication, 1997). It is believed that the temperature dependence observed in the single-monochromator Brewers is attributable to the $NiSO_4$ filter in front of the photomultiplier. In this work we have investigated in detail the temperature behavior of the Brewer MKIV 066 and set up a methodology to reduce the inaccuracies due to this effect.

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2. Experiment

To determine the variation of the spectral responsivity of the Brewer with respect to its internal temperature, as measured by a sensor located near the photomultiplier sensitive end, we have used the mount and the 50 W lamps 94 and 95 supplied by the instrument manufacturer (Sci-Tec, Canada) for monitoring the instrument stability. In addition to these lamps, two other 50 W lamps (911 and 921) have been used for some measurements. The position of the Brewer grating is accurately controlled by a Hg lamp test to ensure proper wavelength calibration before every lamp spectrum. For each lamp at least two measurements, from 290 to 325 nm in steps of 0.5 nm, have been made and averaged. The measurements have been taken along a 5 month period at Brewer internal temperatures ranging from 10°C to 42°C. The Brewer is provided with a heater, which powers on at about 9°C maintaining the internal temperature above 9°–10°C even when the ambient temperature decreases below zero, as often happens in winter at our site. Measurements taken several months apart and at the same temperature were coincident within 2%, confirming the high intrinsic stability of the spectrophotometer. Accurate tests of the ambient temperature effects on the lamp's radiance (which could mistakenly be attributed to Brewer responsivity variations), have been performed in the investigated temperature range. The 50 W lamps, housed in the SCI-TEC mount, have been mounted on the plate supporting the Teflon diffuser of a 4 m long optical fiber connected to a temperature-stabilized double-monochromator spectrophotometer. A rigid black plastic enclosure surrounding both the Sci-Tec lamp

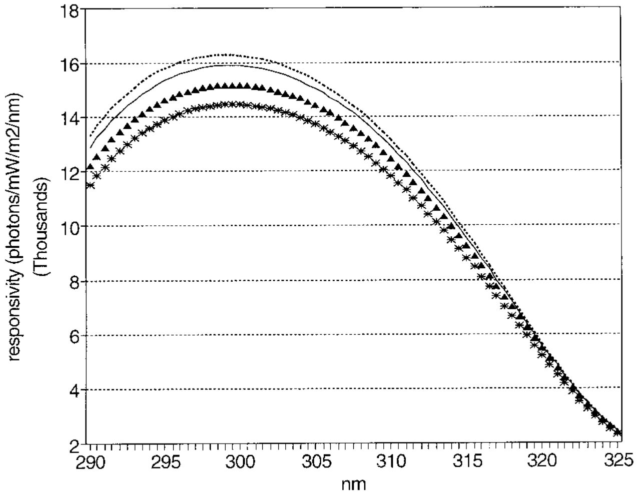

Figure 1. Brewer responsivity curves obtained with lamp 95 at 9.8°C (top curve, dotted), 21.7°C (solid curve), 34.3°C (triangles), and 42°C (asterisks).

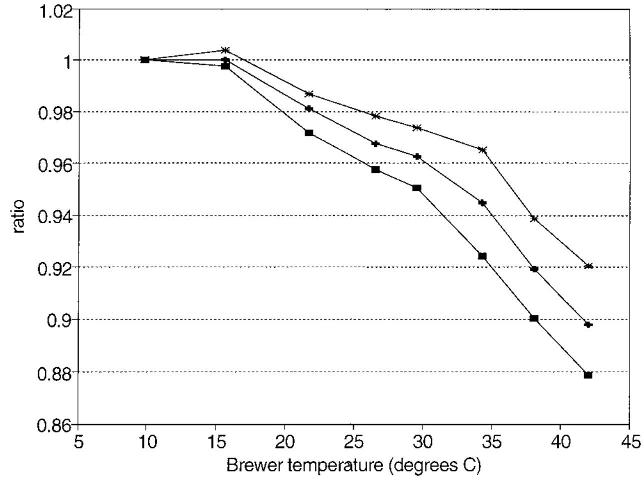

Figure 2. Ratios of the uvres values at 295 nm (squares), 310 nm (pluses), and 320 nm (asterisks) taken at temperatures from 9.8°C–42°C to the corresponding values measured at 9.8°C.

mount and the Teflon diffuser was fixed to the end part of the fiber optical guide. Cold or hot air could be flushed inside the plastic box in order to simulate ambient temperature variations from 15°C to 40°C. No ambient temperature effects on the spectral irradiance of the lamps have been observed, at least within the limits of the measurements accuracy (±2%). This is in agreement with the results reported by *Gillotay* [1997] on the effect of the external ambient temperature on the UV light fluxes of the lamps mounted into his transportable "secondary standard" lamp system. From the Brewer lamp count files, the corresponding Brewer responsivity (uvres) files have been calculated using the lamp-irradiation files determined by measuring at the same Brewer temperature, a 200 W lamp (traceable to the National Institute of Standards and Technology (NIST) standards) and the 50 W lamps. The uncertainty inherent in calibration standards, such as our 200 W lamp, is of the order of 2–3% [*Walker et al.*, 1991; *Weatherhead and Webb*, 1997]. The agreement among the responsivity files obtained at the same temperature for the three lamps was within ±1.5%.

3. Results

Figure 1 shows the responsivity curves obtained from lamp 95 at different temperatures: the decrease of the responsivity of the instrument with increasing temperature is evident. Analogous results have been obtained with the other lamps. Figure 2 displays the ratios of the uvres values at 295, 310, and 320 nm taken at temperatures from 9.8°C–42°C to the corresponding values measured at 9.8°C. The dependence of the ratios on temperature is remarkable, with lower wavelengths being more affected than higher wavelengths. The variation of the ratio with respect to unity is about 12% at 295 nm and about 8% at 320 nm for a temperature variation of 32°C. High-to-low temperature ratios of the responsivity curves for two real cases of clear-sky days in winter (top curve) and in summer are shown in Figure 3. The Brewer internal temperature intervals are 9.8°C–21.7°C for the winter day and 21.7°C–42.0°C for the summer day. While in the winter day the linear fit of the ratio curve increases from 0.97 at 290 nm to 0.99 at 325 nm, for the summer day a steeper variation occurs, increasing from 0.895 at 290 nm to 0.94 at 325 nm. It follows that while in winter (up to about 20°C) the mean inaccuracy over the 290–325 nm spectral range is of the order of 2%, which is within the accuracy of the determination of the uvres, in the warm season the mean inaccuracy could rise by up to 8%. The procedure to reduce the errors induced by the temperature effect is based on the use of a family of responsivity curves such as those shown in Figure 1. The uvres corresponding to any given temperature in the investigated range can be calculated by linear interpolation of the already determined uvres responsivity files. This allows to calculate the correct solar UV spectra using the responsivities corresponding to the temperatures at which the UV measurements have been made during the day. If variations of the Brewer responsivity of 3% or more are detected by the routine calibration stability tests, a new calibration of the instrument has to be performed with a NIST-

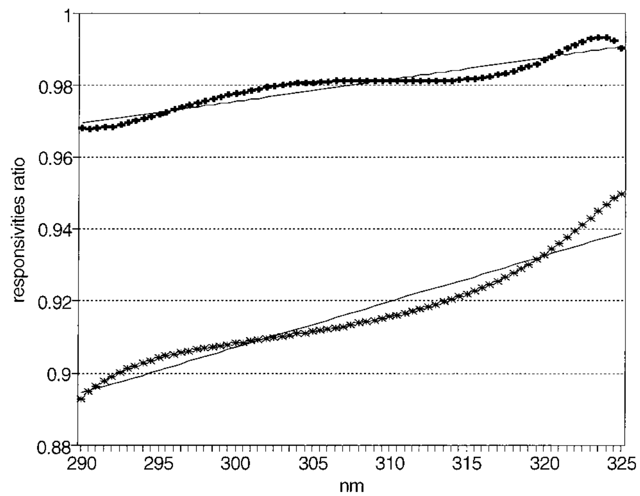

Figure 3. Ratios of the high-to-low temperature uvres curves for two clear-sky days in winter (top curve, pluses) and in summer (bottom curve, asterisks). The temperature values are 9.8°C and 21.7°C for the winter day and 21.7°C and 42.0°C for the summer day. Solid curves represent the linear fits to the data.

referenced lamp. The resulting uvres will define the "normalization" file for the uvres as previously determined with the 50 W lamps and at the same temperature of the new calibration. All other uvres files will be systematically normalized to that file. If the change of the responsivity is higher than 5%, it is advisable to determine a new family of uvres files, obtained from new experimental measurements performed with the 50 W lamps at different Brewer temperatures.

4. Conclusions

Adoption of the described procedure can contribute to improving the accuracy of the solar UV measurements taken mainly in hot days and particularly for diurnal temperature variations exceeding 15°C, as can occur in summer from the early morning to noon, when a cloudless day follows a cloudless night. In these conditions a drift of the response of the Brewer by several percent is observed, while the same temperature variation in cold days (winter) has noticeably less influence, as illustrated in the examples reported in Figure 3. Moreover, since temperature variations are high in the morning and also to a lesser extent in the evening, the use of temperature dependent responsivities will reduce the inaccuracy of the measurements made at high zenith angles, which are, in general, less reliable because already affected by the "cosine" error.

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