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TECHNICAL NOTE

A VALIDATION STUDY OF THE ROBERTSON–BERGER METER

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Abstract—An evaluation of the Robertson–Berger meter was done in order to address the question of whether instrumental and calibration factors can cause what might be interpreted as a change in the ground level solar ultraviolet-B (UV-B) flux. The evaluation consisted of reviewing information about the instrumentation and components in the published literature, a review of the records and procedures in both operations and calibrations, and examination of two instruments including temperature tests of them. It is shown that the instrument is basically stable and that the calibration procedures did not support data drift. There is a slight dependance of the two instruments upon temperature, 0.3°C/y and 0.6°C/y, which is not sufficient to lead to the reported UV-B trends of the order of 0.7 %/y. There is negligible temperature drift in the control electronics.

INTRODUCTION

A study was performed by the University of Michigan for the Chemical Manufacturer's Association's Fluorocarbon Panel to validate the Robertson–Berger ultraviolet-B (UV-B) network (Sharp and Kennedy, 1990). The network was established in the early 70s and has operated since that time. In 1988 Scotto *et al.* published the results from 8 locations showing a negative trend in UV-B, opposite to what would be expected if atmospheric ozone is decreasing. The main purpose of the study was to assess the instrumentation and the calibration to determine if they contributed to the reported UV-B drift. The methodology was to examine published literature on the instrument and its components, review the records and analyze the design and calibration procedures. Unfortunately, two of the six pertinent logbooks were misplaced, preventing an in-depth analysis of the calibration data. In the analysis effort, very little data exist to test for any drift in instrumentation over the 11 y covered in the Scotto paper. Fortunately, the calibration constants obtained with each year were available and were used to examine instrument stability. Temperature tests were run on two instruments to provide additional information on the possibility that the observed trend could be explained by a temperature trend. Our conclusion is that it is unlikely that a trend of −0.7 %/y could be attributed to instrumental factors.

Literature and Data Survey

Published references

The validation of the Robertson–Berger (R–B)† meter network was predicated in part on the use of existing published literature. A major goal of the literature survey was to locate publications that described the long term performance and environmental effects on the meters and the components of the calibration system. Very little data were located that address these issues as they apply to the Robertson–Berger meter network. For example, an RCA 1P39 photodiode, first manufactured in the 1930s, is used as the detector in the R–B meter. The only published data on long term performance is in the RCA Phototube manual (1963) showing decreasing sensitivity operating at 10 mA and > 25 V bias. The R–B meters operate at less than 0.01 mA, 12 V bias and according to Richardson (private communication), much better stability is expected but has not been published.

Data records

An extensive telephone survey was performed to locate the data records as they pertain to the R–B meter network. Six log books have been identified. Unfortunately, the log book that contains the records for the secondary reference calibration results at Temple University has been misplaced, precluding an analysis of these results. The calibration constants and meter histories are contained in existing log books and provide much of the basis for this study.

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†*Abbreviations*: CF, calibration factor, NIST, National Institute for Standards and Technology; NWS, National Weather Service; R–B, Robertson–Berger.

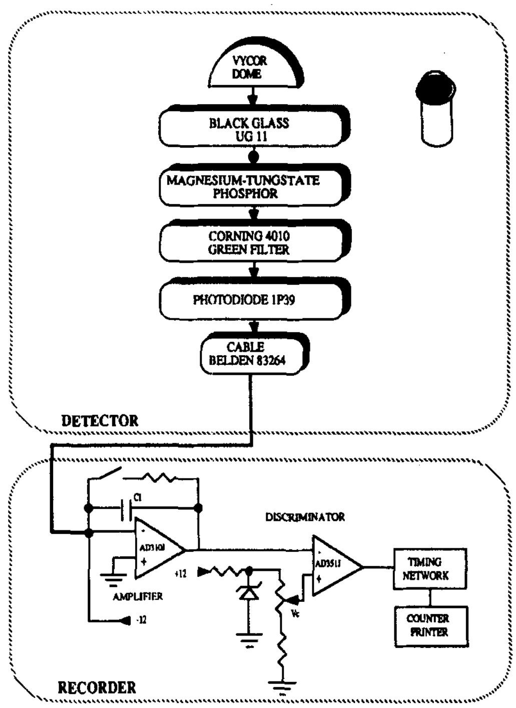

Figure 1. Robertson–Berger meter schematic diagram.

Instrument Design Analysis

Instrument description

The R–B meter was described in detail by Berger (1976). Its operation is summarized here. Figure 1 is a schematic representation of the R–B detector and recorder (electronics). The detector is housed in an aluminium cylinder with a Vycor glass dome to seal the input. The cylinder is vented to the atmosphere through a Drierite desiccant to maintain a dry internal environment. Solar energy enters through the Vycor dome and is first order filtered by a flat piece of UG11 black glass. The magnesium tungstate phosphor deposited directly on the Corning 4010 filter has an absorption (or excitation) spectrum which when convolved with the solar spectrum provides a response function which simulates the human skin erythema action spectrum. The absorbed energy is re-emitted between approximately 400 and 600 nm. This wavelength shift permits the introduction of the Corning 4010 green filter which passes much of the emission from the magnesium tungstate phosphor and blocks the UG11 side band leakage. The final light output is detected by an RCA side window 1P39 vacuum tube photodiode with an S4 bialkali photocathode.

The recorder or electronics unit is mounted in an aluminium chassis box and in all cases was inside a building. Figure 1 shows a schematic of the electronics showing only the elements that directly affect the sensitivity of the electronics. A stable DC power supply provides bias for the photo diode and the electronics. Current flows from the photodiode to the input of the Analog Devices 310J low current amplifier and charges capacitor C1. When the threshold V_c is reached, the output of the discriminator, AD351J changes state providing one count to the timing/counter network and resetting C1. The printout is expressed in counts per half hour. The sensitivity of the electronics is directly proportional to 1/C1 and V_c. Drifts in the system will occur with variations in the components shown in the figure.

Design Analysis

The design analysis looked at environmental factors and long term drift. All elements in the system that affect sensitivity vary with temperature. A temperature test showed that one recorder is very stable and therefore, it's very unlikely that normally operating electronics are of concern. All of the optical elements are expected to change with temperature, but in all cases, except the phosphor, which was measured by Berger (1976), no data were located. With the exception of the phosphor, the other optical elements are relatively broadband and drifts are probably second order to the phosphor temperature variation. Berger (1976) shows that the phosphor temperature coefficient is negative below 320 nm and positive above, suggesting a fairly complex structure. Further temperature data were presented by Blumthaler and Ambach (1986) and temperature test results for two more meters are presented in a later section of this paper.

Moisture could affect the output, but the location of the electronics within buildings and the venting of the detector to atmosphere through a Drierite desiccant means that this is unlikely. Variations in atmospheric pressure were considered but no mechanism is identified to have any effect. Similarly, wind was also considered, but since the meters are relatively small, smooth and well mounted, it's unlikely that wind could have a direct effect.

Snow, rain, or any external contamination certainly affects the output. The procedure was to clean the domes once per week. For yearly trend data most of the UV-B occurs in the summer where snow is not an issue. The effect of rain has not been determined, but the absorption coefficient for water at 300 nm is ~0.005 cm^{-1}. This means a 1% absorption would require a water layer 2 cm thick. The round smooth dome cannot support such a thickness and therefore moisture condensation on the meter does not significantly affect the output. Other contamination with larger absorption could be an issue, but as long as the cleaning procedure was followed this should not be a problem.

Outgassing from materials internal to the detector is exacerbated by the partially closed design. For example, the original Robertson meters had Buna-N O-rings which were later replaced with silicone (Berger, private communication, 1989). Blumthaler noted that detector No. 70's output increased 7.5% when a filter was cleaned (private communication, 1990). Therefore, there is some evidence to suggest that internal contamination did occur and was significant but it was not possible to quantify this effect from existing records and in any event the effect would be removed by the calibration procedure.

Berger (1987) states that "The meter was designed to be as inexpensive and simple as possible. These characteristics are not independent of accuracy or of reliability." For the 28 sites for which calibration factors are available, the average number of repairs per site is 0.8 over approximately 10 y.

Calibration Analysis

Method

In order to perform a long term trend measurement it is necessary to either demonstrate that the instruments are fundamentally stable or to calibrate frequently enough to allow interpolation between the calibrations. In either case, measurements must be made which refer back to a stable source and the only way to determine if a source is stable is to calibrate it absolutely in fundamental units as is done by NIST (National Institute for Standards and Technology). First an absolute calibrated lamp is obtained from NIST. This lamp is compared to the R–B reference lamp several times per year using a spectrophotometer and an integrating sphere, duplicating the NIST method for transferring the absolute calibration. The NIST lamps were replaced after 60 h of operation. The original quartz halogen R–B reference lamp was replaced in 1980 by a xenon arc lamp providing a larger signal. On alternate weeks the R–B reference lamp was used to calibrate two R–B meters which were kept at Temple University. A Schott WG320 sharp cut filter glass was placed between the R–B reference lamp and the R–B standards to simulate the solar spectrum. A Schott WG345 sharp cut filter was used to provide a second spectral point as a measure of spectral shift in the instruments. Dark and open positions were also provided. A mechanical fixture was used to provide repeatable spacing and a time dependent procedure was developed to minimize the effect of lamp heating on the Schott filters. Up to four more R–B meters were used as traveling transfer standards called calibrators. They were first operated on the roof at Temple adjacent to the R–B standards to provide an initial sensitivity. (Note, in Fig. 1, that absolute sensitivity can be adjusted by the potentiometer controlling V_c.) The calibrators were then sent to field sites where they are operated adjacent to the field meters for typically two weeks. The calibrators were then returned to Temple where they were again compared to the R–B standards before being sent to the next field site. Each field site was calibrated once per year.

Calibration data analysis

The calibration data analysis procedures were apparently contained in the missing log books; however, an analysis of the calibration can be performed in general terms. For clarity, environmental parameters are not included in the following equations. The output flux $F_{RBR}(\lambda\Omega)$ of the R–B Reference lamp is determined absolutely by the comparison with the NIST standard, where λ is spectral wavelength and Ω is the solid angle over which the measurements are made. The input, $F_{RBR}(\lambda,\Omega)$, to the instrument under test, i, is passed through a Schott sharp cut filter with a transmission characteristic, $T_F(\lambda,\Omega)$. The absolute output current of detector, i, is then

$$I_{DiABS}(\lambda,\Omega) = S_{DiABS}(\lambda,\Omega) * F_{RBR}(\lambda,\Omega) * T_F(\lambda,\Omega) \quad (1)$$

where $S_{DiABS}(\lambda\Omega)$ is the absolute sensitivity of the detector as a function of wavelength and solid angle. The total detector sensitivity is the convolution integral

$$S_{DiABS} = \frac{I_{DiABS}}{F_{cal}} = \frac{\int_{-\infty}^{\infty}\int_{0}^{\Omega} I_{DiABS}(\lambda,\Omega)d\lambda d\Omega}{\int_{-\infty}^{\infty}\int_{0}^{\Omega} F_{RBR}(\lambda,\Omega)*T_F(\lambda,\Omega)d\lambda d\Omega} \quad (2)$$

The output of the recorder electronics (in counts per half hour) is

$$N_{RiABS} = G_{RiABS}*I_{DiABS} = G_{RiABS}*S_{DiABS}*F_{cal} \quad (3)$$

where G_{RiABS} is the electronic gain of the recorder (adjustable). The absolute sensitivity of the i^{th} meter is

$$S_{MiABS} = \frac{N_{MiABS}}{F_{cal}} = G_{RiABS}*S_{DiABS} \quad (4)$$

A relative measurement of the meter was made using a clear day in June (Berger, private communication, 1990) at local noon in order to relate meter output to sunburn units. For this case a sensitivity can be defined as

$$S_{MiSU} = \frac{N_{Mi}}{F_{SU}} \quad (5)$$

where N_{Mi} is the meter output counts, and F_{SU} is solar input for Sunburn Unit calibration. Since the absolute and sunburn unit sensitivities are the result of convolution integrals, they cannot be related absolutely without additional spectral data which is not available.

A Calibration Factor, CF, was used and is defined as the total number of counts per day for a reference

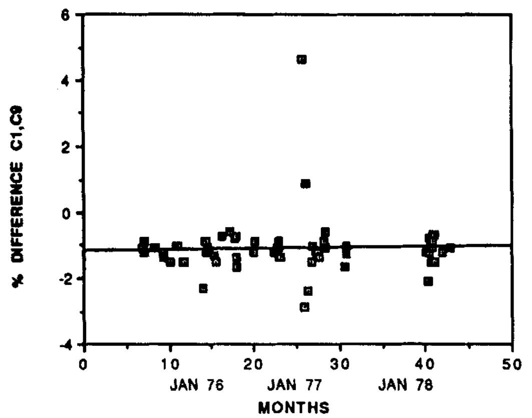

Figure 2. Percent difference *vs* time for a normalized comparison between detectors C1 and C9. Mean = −1.08%, 1 Sigma = 0.7%, Delta = 0.1% in 3 y.

standard meter divided by the total number of counts per day for the *i*th meter measuring in an adjacent location during the same time period (Sharp, 1990, Berger Volume 3, results section).

$$CF = \frac{\sum_{1\,Day} N_{Mref}}{\sum_{1\,Day} N_{Mi}} = \frac{\sum_{1\,Day} S_{Mref}*F}{\sum_{1\,Day} S_{Mi}*F} \quad (6)$$

Note that the sensitivity of the meters, S_{Mi}, is a function of the spectral shape or the input flux, F. Consequently, since the spectral shape of F varies with solar angle, a method was developed to provide a determination of spectral shift. Data from a full day's run between two meters were compared by normalizing a 10:30 a.m. local time and the normalized total difference is divided by the normalized daily total and converted to %. A change in this number would indicate a spectral shift since the sun's output shifts spectrally as a function of zenith angle (CIAP, 1975). The only data available are a comparison between detectors C1 and C9 (which were the two located in Philadelphia) from July, 1975 to July, 1978 and are shown in Fig. 2.

Calibration of the meters at the measurement sites is done by a comparison with the traveling calibrators which are in turn calibrated against the reference standard meters in Philadelphia. Calibration factors for the *i*th field meter are reported and are calculated by

$$CF_{Mi} = \frac{\sum_{1\,Day} N_{MTC}}{\sum_{1\,Day} N_{Mi}} *CF_{TC} = \frac{\sum_{1\,Day} N_{MTC}}{\sum_{1\,Day} N_{Mi}} * \frac{\sum_{1\,Day} N_{Mref}}{\sum_{1\,Day} N_{MTC}} \quad (7)$$

where CF_{TC} is the calibration factor for the traveling calibrator determined by a comparison with the reference standard meters in Philadelphia before and after each field site visit. Presumably, CF_{TC} is the average of the before and after calibrations of the traveling calibrator. The reference standards at Philadelphia were readjusted as needed to maintain calibration factors at unity.

Data analysis apparently is performed by dividing the daily averages for a particular meter by the calibration factors. In Scotto (1988), *e.g.* the results are expressed in counts per 10 000/y and calibration factors are applied by interpolation where possible or by using the last known CF on existing data (Scotto, private communication, 1990). A daily total then, would be

$$N_{DTCalculated} = N_{DTmeasured}*CF \quad (8)$$

Errors

There are, generally speaking, errors that average to zero, random or pseudo-random, and errors that do not average to zero, systematic. Systematic errors can provide an erroneous trend indication. Errors that average to zero add variation to the data, decreasing the possibility that data quality will pass standard statistical tests. The calibration system has been examined for these errors in order to validate the results.

The limit of the system is determined by the absolute calibration of the NIST reference lamp on which the entire calibration system is based. This error is ±2% (Saunders and Shumaker, 1977) and most likely averages to zero over a long period of time. The lamps degrade at typically 10 %/300 h of operation and were replaced every 60 h, which may contribute up to 2% or more variation depending on how the lamps are recalibrated and the data analyzed. The comparison of the R–B reference lamp to the NIST lamp duplicates the procedure described by Saunders and Shumaker (1977). Since this was a frequently repeated measurement, apparently using the same setup, it's unlikely that a systematic drift occurred. Saunders and Shumaker (1977) indicate a repeatability of 0.72% for a similar measurement. It's unlikely that the R–B calibration operations are better than those of NIST who perform this function full time. Since the log books are missing, a means to estimate the measurement errors that might be expected are provided in Torr *et al.* (1977). In that study 10 reference sources from 10 sites were intercompared at the University of Michigan. At 400 nm, the shortest wavelength measured, the mean error for all 10 sources was 28 %. Therefore, since the R–B calibrations were made repeatedly, typically by the same people, it would be expected that variations introduced by operators would produce an accuracy much closer to the NIST's 0.72% than to the 28% found by Torr *et al.* (1977).

The comparison of the R–B reference to the R–B standards has the potential for larger random errors since it appears that the lamp heated the Schott filters enough to cause an unspecified transmission change to the extent that readings were taken at a specified time from lamp turn-on. As long as the measurement time was repeated, the effect would be to decrease variability. As noted above, the WG320 filter was used to simulate the solar spectrum and the WG345 was included to provide a measure of spectral response. The methodology for predicting spectral effects is not known; however, the WG filters' spectral transmissions were not monitored and the filters have been misplaced. Clearly, a long term drift in transmission of the WG320 filter would appear as a long term trend. Schott's R. Sheller (private communication, 1990) states that these color glasses are expected to drift with time but the effect has not been quantified. Berger (private communication, 1990), states that these filters were used in other applications at Temple and showed no indication of drift. Therefore, while it's probably true that the color glass filters were reasonably stable, it has not been conclusively demonstrated.

The calibration system does not provide instrument sensitivity as a function of wavelength. An analysis could be performed based on reasonable models for shifts in the meter spectral signatures to determine if the lack of a detailed spectral calibration significantly affects the final results. In the next section, however, it will be shown that the average drift of the calibration factors is 0.6 %/y. With such small changes in overall sensitivity, it's very unlikely that a detailed analysis will show that changes in spectral signature are significant.

The remaining steps in the calibration consist of placing meters side by side, either at Temple with the R–B Standards or in the field with Calibrators. Since the meters are not particularly sensitive to physical placement and were mounted in simple brackets, the repeatability due to physical setup would be expected to be very good. Field site calibrations were repeated once per year which appears adequate based on calibration factor data shown in the next section. Also, as will be seen in the temperature test section, the meter sensitivities and spectral responses change with temperature and therefore the calibration will depend on the ambient temperature. Since calibrations are performed once per year, the ambient temperature effect will introduce variability to the data and may not average to zero.

Analysis of calibration factors

Two sources of data were available for analysis of the overall calibration of the instruments. The first was a listing of "Calibration Factors", CF, contained in Berger Log Volume 3. The second was a subset of Calibration Factors obtained from Scotto for the sites used in Scotto *et al.* (1988). An overlay of the CF from the two sources should, in principle, agree, and generally the agreement is very good. Figure 3(a) and (b), Ft. Worth and Mauna Loa,

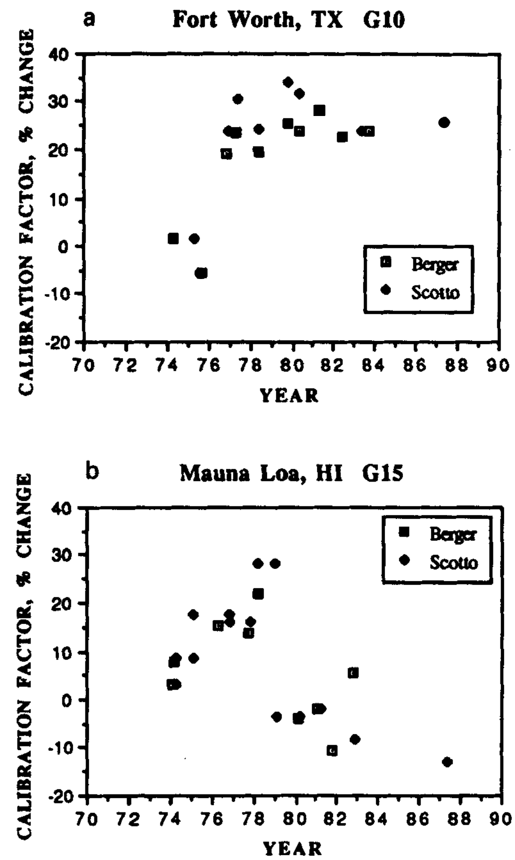

Figure 3. (a) Fort Worth calibration factor % change overlay. (b) Mauna Loa calibration factor % change overlay.

however, show some unexplained discrepancies, possibly due to data transcription errors. For example, in Fig. 3(a), about 1980 the Berger CF are lower than the Scotto values, and yet Berger is the only source for the numbers. The 1981 and 1982 data agree very well, however. In principle there shouldn't be any processing of the CF between Berger and Scotto, so it may be that simple transcription errors occurred as are common today with the modern FAX machine.

Figure 4 shows a worst case representative sample of CF plotted *vs* time. The records were examined

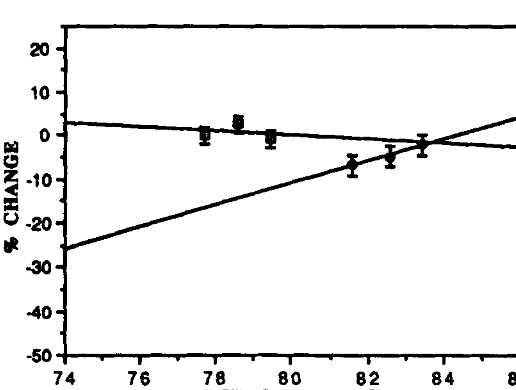

Figure 4. Detroit's calibration drift % per year.

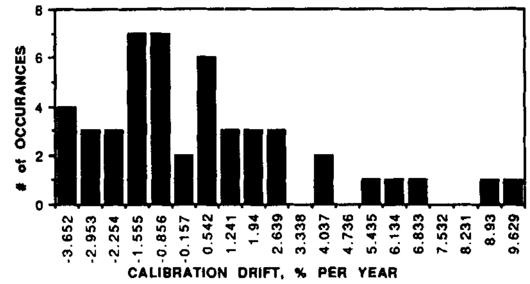

Figure 5. Calibration factor drift in R–B meters, 46 cities, average = 0.593.

to identify systematic changes in the instrument configuration. The CF data records were then segmented and curve fit with a regression analysis to obtain slopes for each segment. In some cases, as in Fig. 4, a distinct change in slope was not accompanied by a recorded systematic change. An analysis of the calibration factor slope data shows a standard deviation of 8.5 % for random errors.

The slope data were then subjected to the Lilliefors Normality test (Bevington, 1969) for data validity. Two slopes, one from Mauna Loa and the other from New Orleans, failed the Lilliefors test (were outside the normal distribution). These two slopes were discarded because they were based on only two data points. A mean and standard deviation were then calculated on the remaining 46 slope data points plotted as a bar chart in Fig. 5. The average CF drift is 0.593 %/y with a 1 σ variance of 1.07 %/y. Therefore, the confidence level that the mean drift is statistically significant is 76%.

If one assumes that the CF drift was in the calibration system and the meters were stable, then the Scotto *et al.* (1988) data would need to be corrected. Recall that the calculated counts are the raw data counts multiplied by the calibration factors. To get back to raw data, the Scotto *et al.* (1988) results would need to be divided by the calibration factors. Since the CF increase an average of 0.593 %/y then Scotto's reported mean decrease of 0.7 %/y would change to a decrease of 1.3 %/y if the 0.593 %/y drift was due to the calibration system. If the 0.593 %/y average drift is in the meters and the calibration is stable, Scotto's result are unchanged. Therefore, either scenario shows a negative trend in UV-B.

Analysis of Bismark, Tallahassee, and Mauna Loa data

John Frederick (this issue) and John DeLuisi (this issue) have provided additional analysis of the R–B data which tends to show that the calibration is stable after accounting for systematic errors. Frederick has analyzed the Bismark and Tallahasse R–B data in detail and notes that there is no apparent trend in the summer months but a significant downward trend in the winter months which agrees with Scotto *et al.* (1988). The calibration factor analysis contained herein shows a small, slow drift and consequently will not account for the summer/winter difference. Since no trend is seen in summer, then it is most probable that the calibration system performed properly.

Mauna Loa data for 11:00 to 11:30 a.m. provided by J. Scotto has been analyzed by John DeLuisi and compared to Dobson meter data with the Bird model (private communication, 1990). Mauna Loa was chosen for this analysis because it is expected to have a clean atmosphere, a Dobson meter is nearby and it is usually cloud free in the mornings. Therefore, it was expected that the only effect on the R–B meter input would be stratospheric ozone for which account could be taken with a suitable model. In Table 1, columns 1 and 2 were taken from the DeLuisi plot and correspond to the dates when calibrations were performed. Column 3 lists the calibration factors obtained from Scotto. Column 4 contain CF that are corrected for apparent systematic changes. The third number in column 4 is an interpolation between the 2 and 4th numbers. The fifth number is the original calibration factor found in Berger Logbook 3, and the last number is scaled by the ratio of the 4th numbers, *i.e.* $0.996 = 0.870 \times (1.05/.917)$. It appears that a change in calibration factor calculation occurred in 1982 and continued for the rest of the program for Mauna Loa. Column 5 contains the ratio adjusted by the corrected calibration factors and column 6 is the ratio with calibration factors removed by dividing column 2 by column 3. Adding corrections in Fig. 6 shows a negligibly small slope of −0.05 %/y. This analysis would suggest that the calibration system was basically stable but that a systematic error in the Mauna Loa calibration factor occurred in 1982.

Figure 7 is a replot of the Scotto *et al.* (1988) data with all cities summed to see if a consistent change occurred. There is a clear shift in the data in 1982, but abrupt jumps also occur in 1975 and 1980. DeLuisi's data do not include 1975 but there may be a correlation with 1980 suggesting that another systematic error occurred in 1980. This may be due to the change from the halogen to the xenon reference lamp in 1980.

Temperature Tests

Test setup

Temperature drift of the R–B meters was identified as a probable major source of variation in the UV–B data. Since the only data available were the original curve of Berger (1976) which only looked at the phosphor and the result of Blumthaler *et al.* (1989), a limited test was performed to provide additional information. The basic test consisted of

Table 1. Mauna Loa data

1 Date	2 R-B/Bird ratio W/CF	3 Scotto CF	4 Corrected CF	5 R-B/Bird ratio W/CF corrected	6 R-B/Bird ratio W/O CF
03/15/78	785.70	1.284	1.284	785.70	611.92
02/01/79	775.80	0.963	0.963	775.80	805.61
03/15/80	742.50	0.963	0.972	749.40	771.03
01/11/82	775.80	0.982	0.982	775.80	790.02
11/09/82	693.00	0.917	1.050	793.50	755.73
04/15/87	670.50	0.870	0.996	767.60	770.69

placing two meters on the roof of the Space Research Building at the University of Michigan. The input to the meters was natural solar light. One meter, called the reference, was wrapped with heat tape and controlled to a nominal 40°C. The meter under test was installed in a standard Tenney Jr. laboratory thermal chamber. After completion of the first series of tests the meters were interchanged. The test temperature range was −20°C–40°C. Both instruments' diffuse light viewing 2π steradian field of views were somewhat compromised by the limitations of the test setup. Direct sunlight was not affected. The R–B meter recorder electronics were located inside the building. Measurements were performed continuously with the exception of shutdown for two thunderstorms.

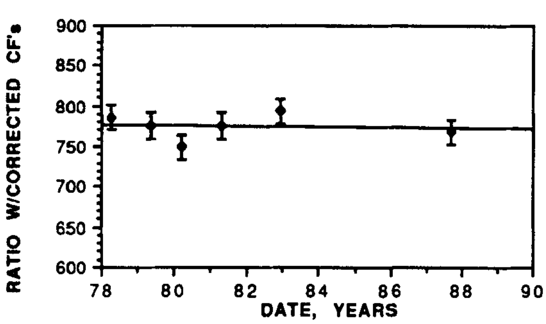

Figure 6. Mauna Loa R–B to Bird model ratio with corrected CF.

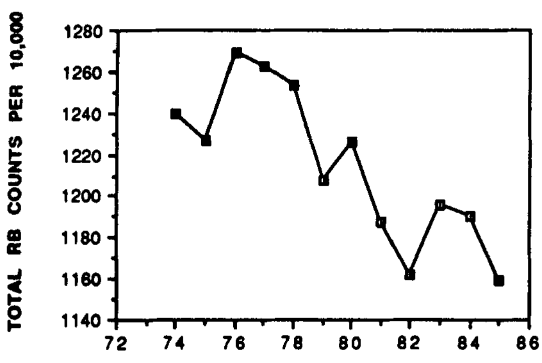

Figure 7. Scotto *et al.* (1988) data summed for all cities. The two missing data points in the data set were included by interpolation.

Ancillary test data

Ancillary test data were collected from the National Weather Service, NWS, and from the University of Michigan solar station. The NWS data was obtained through the WSI worldwide Real-Time Information System and the University of Michigan data were obtained from MERIT network.

Test results

The R–B meter C15 was run through the nominal temperatures with C54, the reference meter, for approximately two weeks. The meters were then switched and tested again. The nominal temperatures were −20°, 0°C, 20°, 40°C. The meters were set up on 5/22/90 and operated until 6/22/90 with the meters being switched on 6/8/90. Each meter was tested under each temperature approximately 3–4 times.

The meter was studied using an Infra Red camera for a day, to understand the temperature gradients throughout the meter. The aluminium cylinder was found to have a uniform gradient across it, while the flange and dome operated at lower temperatures, apparently following the air temperature.

The 150 W heat tape on the reference meter was chosen to be of low power in order to minimize the possibility of overheating and damage to the R–B meter. Consequently, the reference temperature was not absolutely controlled. Figure 8 shows the effects of a light rainy day. The Tenney Jr. oven temperature inside, R26/C15 inside, is held fairly constant at 41°C, while R26/C15 outside, the temperature outside the oven, seemed to follow the air temperature. The reference temperature, R45/C54, is too low because of rain cooling the heat tape and was held at 31°C on 6/20/90.

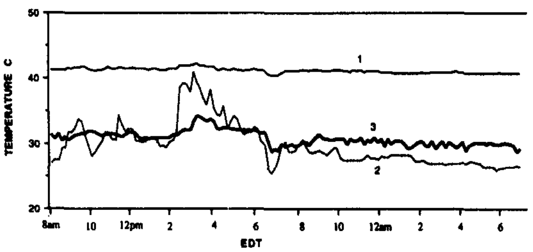

Figure 8. Temperature in R–B meters on 6/20/90, 1. Temp R26/C15 inside, average = 41.08°C; 2. Temp R26/C15 outside, average = 29.75°C; 3. Temp R45/C54, average = 30.76°C.

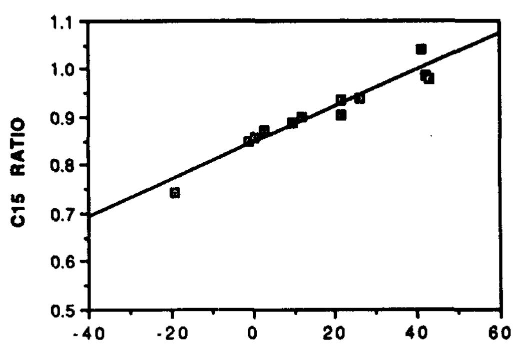

Figure 9. Temperature coefficient for meter C15 at 2 p.m. EDT.

Data analysis

The output of the meters was recorded each day and converted into a ratio. The ratio of the SUV counts was calculated by dividing the test meter's output by the reference meter's output adjusted to a reference temperature of 40°C. The temperature coefficient was found by iterating the slopes of the ratio plots. The slopes were iterated until there was agreement of the temperature coefficient up to 5 decimal places. Figures 9 and 10 are the temperature coefficients for meters C15 and C54 at 2 p.m. eastern daylight time. The figures show that a temperature coefficient of 0.38 % and 0.55 % were found

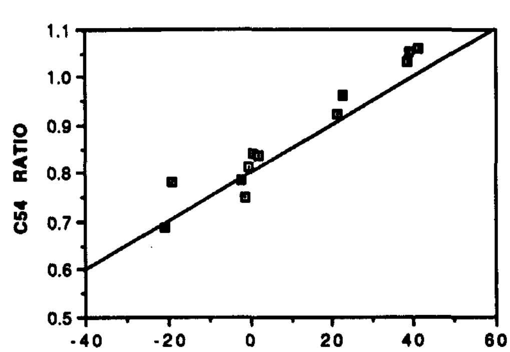

Figure 10. Temperature coefficient of meter C54 at 2 p.m. EDT.

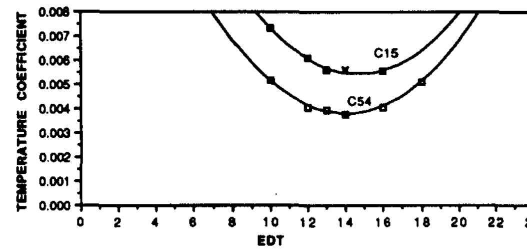

Figure 11. Temperature coefficient of the R–B meters *vs* time or sun angle.

for meters C15 and C54, respectively. They compare with the 0.8 % observed by Blumthaler and Ambach (1986). Karl (1984) shows that temperatures change by as much as 4°C in the US between 1974 and 1983. For a 0.7 %/y change in ozone over 11 y (7.7 % total) the instrument temperature coefficient would need to be 7.7 %/4°C = 1.9 %/°C. While a detailed analysis of instrument temperature coefficients and local temperature at each site could be performed, it is unlikely that the mean temperature coefficient differs from the three measured.

The temperature coefficient was plotted against time to show the effect of sun angle. Figure 11 shows that the meters temperature coefficient follows the same path over time except for the shift in each meters actual coefficient. The curves are centered at 2 p.m. and approximately 2:15 p.m. The curves are centered here because the local noon in Detroit in June is 2 p.m. The slight difference in the low point of the curves is probably due to the ½ h granularity in the R–B meter printout.

Conclusions

The Robertson–Berger UV-B monitoring network was examined to determine primarily whether UV-B trend results reported by Scotto *et al.* (1988), *e.g.* could be attributed to instrumentation or calibration trends. It is our conclusion that it is unlikely that the trend on the order of the −0.7 %/y reported by Scotto can be attributed to instrumental effects. Although it is possible that an artificial trend could be attributed to drift of the WG320 glass filter in the calibration system, this conclusion is not supported by the summer time trend analysis at Bismarck or Tallahassee nor is it supported by a comparison with the Dobson meter at Mauna Loa when a systematic shift in the calibration factor is included from 1982 on. Moreover, if the filter drifts towards longer wavelengths, its effect would be to show an even more negative trend.

Temperature coefficients of 0.3 %/°C and 0.6 %/°C for two instruments were measured. Blumthaler and Ambach (1986) reported 0.8 %/°C. Assuming the remaining instruments fall within this range, then a mean temperature decrease between 10°C and 25°C over 11 y would be needed to produce the 0.7 %/y reported by Scotto *et al.* (1988).

Since this large a change appears unlikely, the conclusion is that temperature drift is not a significant factor in trends of this magnitude. Local temperature variations, however, can contribute significantly to the variability of the data. The design analysis of the electronics indicates that electronics should be adequately stable. A test of one electronics unit shows temperature drift to be negligible.

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