Some Characteristics of Solar Ultraviolet Radiometers

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ABSTRACT

Solar and terrestrial radiometers normally degrade with time and should ideally be recalibrated at leasty once a year for reliable operation. However, recalibration is often difficult for developing countries because of the inherent costs involved. The degradatioon in the sensitivity in different radiometers can vary markedly. In this paper the performance of two previously installed radiometers, an Eppley Laboratories Total Ultraviolet radiometer (TUVR) and an Eppley Laboratories Precision Spectral Pyranometer (PSP) are compared with two new and identical models. Over an average period of approximately six years, the older TUVR indicated a decline of over 40% in sensitivity. By using a technique of data smoothing of a discrete time series followed by a least-squares polynomial fit, the authors show that the data from the degraded TUVR can be recovered to an agreement of better than 0.17%. Therefore, if the calibration curve can be obtained for a given TUVR, correcting of the radiometer would be straightforward using the method described.

1. INTRODUCTION

The manufacturers of solar radiation measurement instruments (radiometers) recommend that their instruments be calibrated regularly, typically once a year. While this method is the ideal way to use the instruments it is a bit problematic to adhere to, especially when the user is in the developing world; primarily due to the inherent costs and disruption to the records of data associated with the regular calibration. In many such instances, the instruments are used for progressively longer (than one-year) periods before they get shipped out fore re-calibration. Two problems arise due to the requirement for calibration; namely that: (i) the operator normally cannot afford to have more than one such instrument at any time, this means that when the instrument is sent to the manufacturer for re-calibration, no data can be recorded (a loss in the continuity of data records), and (ii) the actual cost of shipping to and from the manufacturer, and the cost of re-calibration are usually beyond the annual budgets of the user.

The result of using the instruments for longer periods than that recommended for re-calibration is obviously that such data as recorded after the recommended re-calibration period are unreliable. In some instruments the change in the calibration parameters over a short period of say two years is insignificant, but in others the change could be quite significant. These changes in the calibration parameters are typically due to the design and construction of the instrument. Hence different instruments will show different deterioration characterisitics with time. In the present study two types of radiometers have been studied. The two instruments studied are the Precision Spectral Pyranometer (PSP) and the Total Ultraviolet Radiometer (TUVR), body of which are manufactured by Eppley Laboratories of the USA. The performance of these instruments has been studied over the years 1992 to 1998 inclusive, a period of seven years. While the PSP did not show a significant change in its sensitivity over the study period, the TUVR showed a fall of over 40% in its sensitivity over a period of approximately 5 years. Khogali and Al-Bar [1] also reported a decrease in the sensitivity of a TUVR used for studies of ultraviolet (UV) radiation in Makkah in Saudi Arabia.

1.2 Design of the Instruments

The TUVR consists of a selenium barrier-layer photoelectric cell with a sealed-in quartz window, a band-pass (interference) filter to restrict the wavelength response of the cell to 295 nm to 385 nm, and a teflon diffusing disk. The diffusing disk reduces the light intensity at the photocell (and thus increases stability with exposure time), and also improves the instruments adherence to the Lambert cosine law, Eppley Laboratories [2].

The PSP comprises of a circular multi-junction wire-wound thermopile. The thermopile has the ability to withstand severe mechanical vibration and shock. The receiver is coated with Parsonís black lacquer. The instrument is supplied with a pair of precision ground and polished hemispheres of Schott clear WG295 optical glass; Eppley Laboratories [3].

2. METHODOLOGY

Global solar radiation and global solar ultraviolet radiation data have been recorded using an Eppley pyranometer model PSP, and an Eppley total ultraviolet radiometer model TUVR, as the sensors, respectively. The data have been recorded using a Kipp and Zonen model CC14 Solar Integrator (and a back-up data logger designed around the IBM PC) continuously, at the University of Botswana, from February 1992. In October 1996, a new Eppley TUVR was acquired and installed next to the old TUVR to compare the readings between the old and the new TUVRs. The recorded data (which are the daily totals) were plotted, and are shown in Figs. 1 and 2. Figure 1 shows the total solar radiation, whereas Fig. 2 shows the total ultraviolet radiation. The data recorded by the new TUVR were compared to those recorded by the old TUVR, starting from the day the new TUVR was installed in October 1996. Comparing the data recorded by the two instruments at the end of the first day, it was found that the old instruments reading was 52.8% lower than that of the new instrument. Clearly, the sensitivity of the old TUVR has been affected by its long exposure to the weather at the research site.

3. RESULTS AND ANALYSIS

It is clearly observed from the graph of the measured UV radiation against time (day-number), shown in Fig. 2, that there is downward trend in the recorded data for the old TUVR, in addition to the annual seasonal variation of the ultraviolet radiation. The new TUVR also shows this downward trend, for the period that it has been in operation (from 1996 to 1998). Compared with data recorded by the PSP (the total or global solar radiation, shown in Fig. 1), the response of the PSP does not depict any downward trend as that shown in Fig. 2 for the TUVR.

The seasonal variation in the recorded data can be filtered out to give de-seasonalized data using time-series analysis. The kind of analysis of a time series which exhibits a trend depends on whether one wants to (a) measure the trend or (b) remove the trend in order to analyze

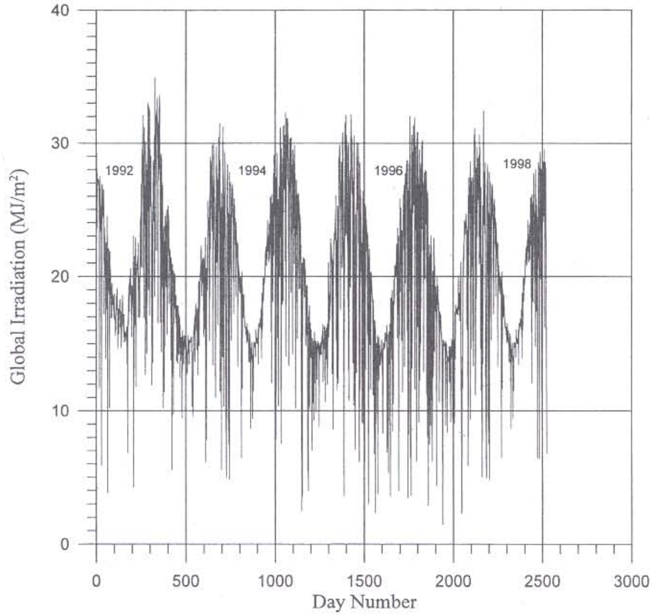

Fig. 1 Total solar radiation recorded by an Eppley pyranometer (1992-1998).

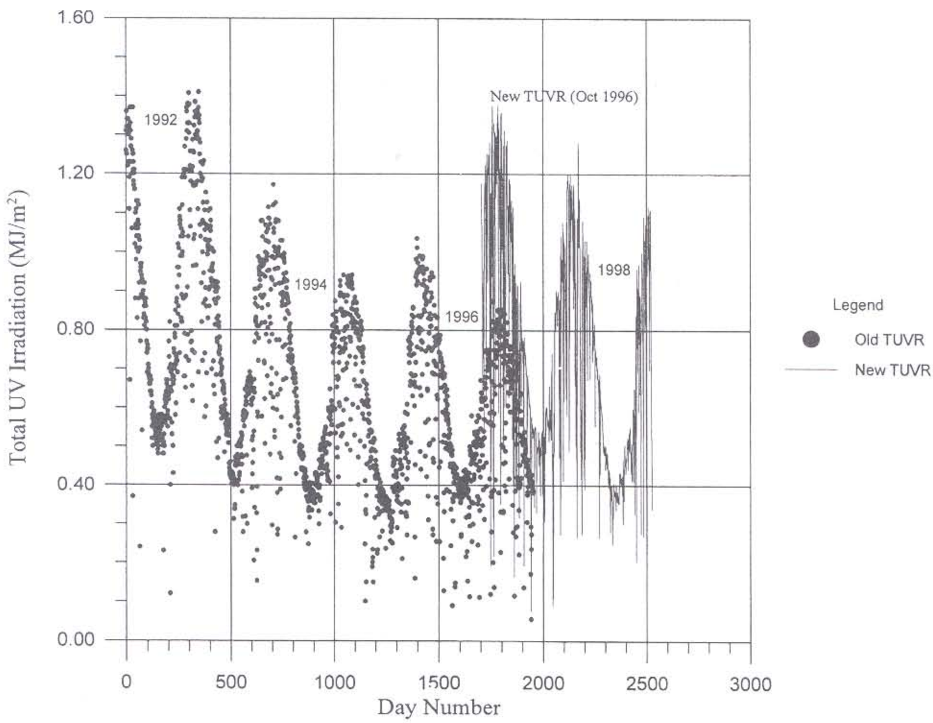

Fig. 2 Total solar ultraviolet radiation as recorded by two Eppley ultraviolet radiometer models (TUVR).

local variations. In the present analysis it is needed to measure the trend in the recorded UV radiation, hence the local fluctuations need to be removed; that is a low-pass filter must be applied to the data. The linear filter used, referred to as a moving average, will convert the time series $\{x_t\}$ to a new series of smoothed data $\{y_t\}$:

$$y_t = \sum_{r=-q}^{+q} a_r x_{t+r} \tag{1}$$

where $\{a_r\}$ is a set of weights that are chosen so that $\Sigma a_r = 1$ [4, 5]. The method used here is that of a symmetric smoothing filter, the moving average, where $a_j = a_{-j}$, that is for which $a_r = 1/(2q+1)$ for $r = -q, \ldots, +q$; then the smoothed value of $\{x_t\}$ is given by

$$Sm\,(x_t) = [1/(2q+1)] \sum_{r=-q}^{+q} x_{t+r} \tag{2}$$

This method of data smoothing has been applied to the data recorded by the old TUVR, for a smoothing period or cycle $(2q+1)$ of a year. The resulting curve was plotted to the same scale as the original data, and is given in Fig. 3. This figure clearly shows the downward trend in the sensitivity of the TUVR.

Least-squares curve fitting can be applied to the smoothed curve to find a suitable function for the curve. Several methods of fitting a curve are possible: namely the linear fit (based on the equation $y = a + bx$), exponential fit (based on the equation $y = ae^{bx}$), power fit (based on the equation $y = ax^b$) and the polynomial fit (based on the equation $y = a_o + a_1x + a_2x^2 + a_3x^3 \ldots a_nx^n$). The curve fitting method of Golden Software's Grapher program [6], was applied to the smoothed curve to determine a suitable function to give a best fit to the smoothed curve. A second order polynomial curve-fit gave the best fit statistics, namely: the lowest residual sum of squares (SSe), and a very high coefficient of determining R^2 of 0.9916. The curve fit is shown in Fig. 4.

The polynomial fit resulting from the analysis has been used to correct the data that were recorded by the old TUVR. The corrected data, shown in Fig. 5, produce a remarkable fit to the

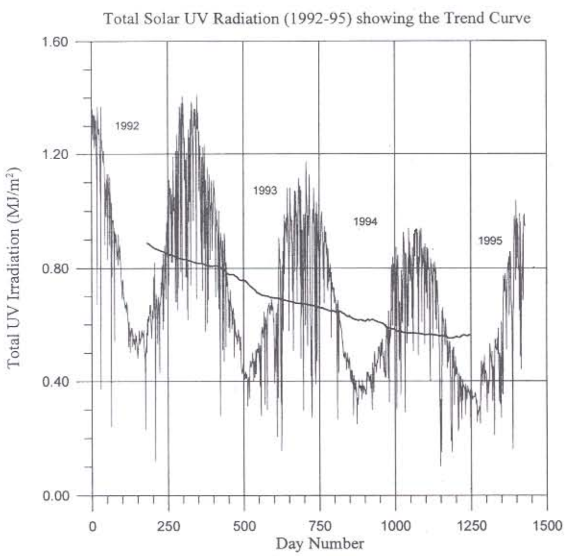

Fig. 3. The total ultraviolet radiation as recorded by the old TUVR showing the trend curve.

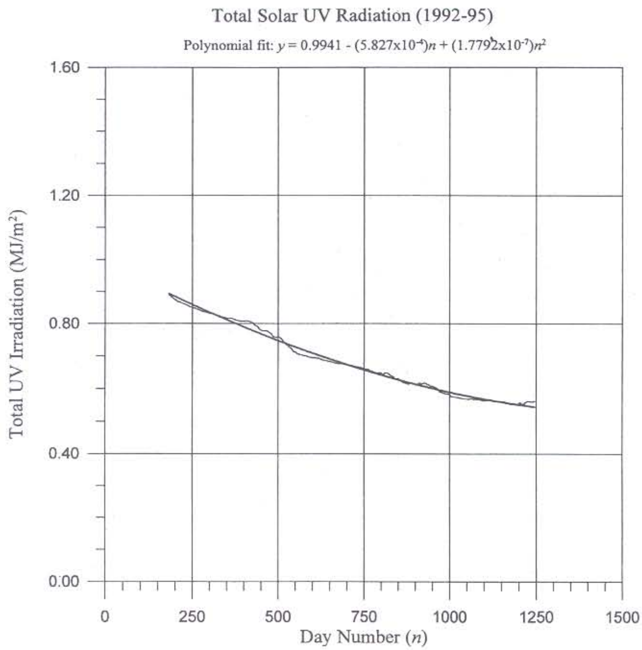

Fig. 4. The trend in the recorded solar UV fitted with a polynomial curve of second order.

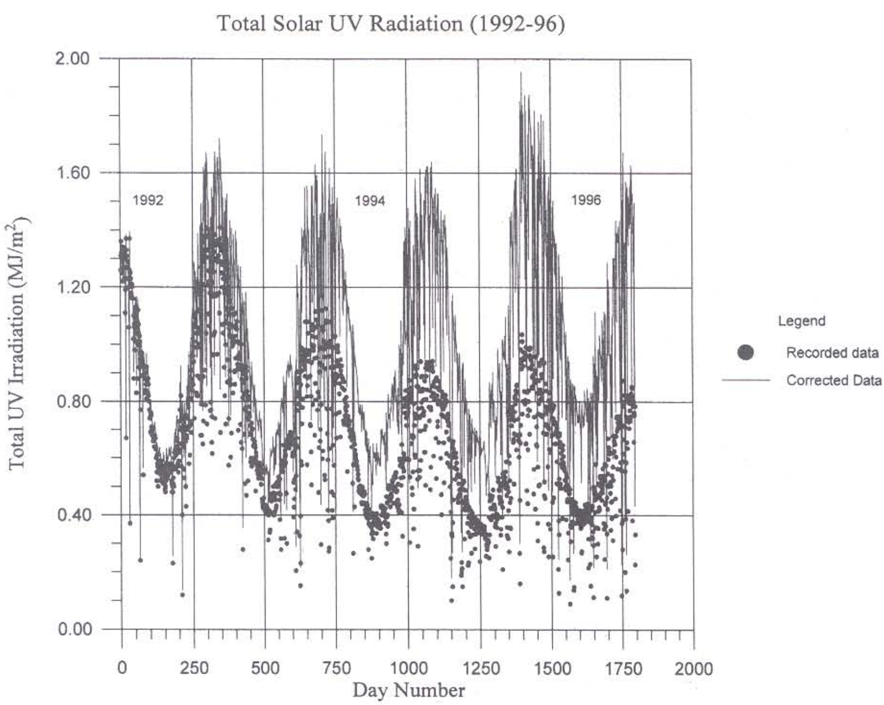

Fig. 5 Comparison of the recorded UV and the corrected UV data for the period 1992-1996.

data recorded by the new TUVR in October 1996. In fact comparing the reading of the new TUVR and the corrected data for the first day of recording in October 1996, it is observed that the difference between the two results is only 0.17%, a remarkable result indeed.

4. CONCLUSIONS

It can be observed from Figs. 2, 3 and 4, that the sensitivity of the Eppley TUVR has progressively become lower with time. The exposure of the instrument to the extremes of the weather in Botswana must have affected its performance over this long period. As stated earlier, this deterioration in the performance of the instrument must be attributed to the design and construction of this instrument; since the Eppley pyranometer, model PSP has shown to be immune to the same weather conditions (Fig. 1). In particular, the user needs to be adequately informed that the instrument can show this deterioration if used in a climate like Botswana's semi-arid and very hot type.

If a calibrated curve like that in Fig. 4 can be given for the instrument, then it would be an easy task to correct for this reduced sensitivity of the TUVR, and then obtain reliable data for the ultraviolet radiation recorded.

5. ACKNOWLEDGEMENTS

The authors would like to acknowledge with gratitude the financial support from the Research and Publications Committee of the University of Botswana, who funded some aspects of this research project.

6. REFERENCES

1. Khogali, A., and Al-Bar, O.F. 1992. A study of solar ultraviolet radiation at Makkah solar station. *Solar Energy* 48(2): 79-87.
2. Eppley Laboratories. 1993. *User Manual for the Total Ultraviolet Radiometer, Model TUVR*. U.S.A.: Eppley Laboratories.
3. Eppley Laboratories. 1993. *User Manual for the Precision Spectral Pyranometer, Model PSP*. U.S.A.: Eppley Laboratories
4. Chatfield, C. 1989. *The Analysis of Time Series*, Fourth Edition. London: Chapman and Hall.
5. Kendall, M.G.; Stuart, A.; and Ord, J.K. 1983. *The Advanced Theory of Statistics*, Vol. 3, Fourth Edition. London: Griffin.
6. Golden Software, Inc. 1994. *Grapher for Windows, Reference Manual.* U.S.A.: Golden Software, Inc.