Solar UVR instrument inter-comparison focussing on measurement interval recording setting and solar zenith angle as important factors

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Abstract
Solar ultraviolet radiation (UVR) data for matching time periods between November 2014 and February 2015 were recorded by two instruments, namely a UVR biometer and a Davis UVR sensor, and their data were compared. Several checks and challenges were identified during the data preparation stage. The measurement interval of the biometer was changed from 30-minutes to 1 hour which prompted the recalculation of readings measured by the Davis UVR sensor for the periods affected. On average, the Davis UVR sensor slightly overestimated solar UVR levels when compared to the biometer data and this relationship was strongest for small solar zenith angles (SZA) when the sun was high in the sky. Further research is necessary to investigate the influence of other external factors that may influence the differences in the two instruments' solar UVR measurements, such as instrument hardware in the form of fins on the Davis UVR sensor housing.

Keywords: solar ultraviolet radiation, solar zenith angle, Pretoria.

1. Introduction

Solar ultraviolet radiation (UVR) has beneficial and harmful effects on ecosystems, animals and humans. Monitoring ambient (surface) solar UVR is important to detect trends and patterns, particularly in the context of global stratospheric ozone depletion. Various instruments are commercially available for science-grade measuring of solar UVR. Comparing measurements made by different instruments helps one understand the importance of critical factors and related considerations, to make meaningful deductions from the data.

By comparing two solar UVR instruments, namely, a UV biometer and a Davis Vantage Pro2 UVR Detector, we look at an important factor influencing ambient solar UVR, namely SZA, and its impact on solar UVR measurements and we highlight some of the important checks to make when comparing data measured by different instruments for the same time period.

2. Data and Methods

Data were collected from two instruments located at the South African Weather Service (SAWS) Head Office and the Council for Scientific and Industrial Research (CSIR) Defence Peace Safety and Security (DPSS) Building in Pretoria (25.7° S, 28.2° E, altitude ~ 1 340 m), respectively.

A UV Biometer (model 501), comprising a Robertson-Berger pattern UVR detector, digital recorder and control unit, is used to measure ambient solar UVR levels at the Pretoria SAWS head office. The UV Biometer spectral response closely mimics the McKinley/Diffey Erythemal Action Spectrum (280-340 nm) (CIE, 1987). Calibration of the UV Biometer enables the logged values to be converted into MED (Minimal Erythemal Dose, where 1 MED = 210 Jm^{-2} for skin phototype I) per hour or per 30-minutes (see Table 1 for 1-hr versus 30 minute measurement periods). The SAWS instrument measurement interval was changed for unknown reasons and dictated the interval period used for the inter-comparison.

Recently, the Pretoria UV Biometer was inter-compared with a travelling standard instrument calibrated against the fast scanning spectro-radiometer SPECTRO 320D NO 15 that has traceability to the International Bureau of Weights and Measures. Analysis found the difference in the instrument pre- and post-calibration was less than 4%.

The Davis Vantage Pro2 UV detector comprises a transducer which is a semiconductor photodiode with a spectral response that matches the McKinley/Diffey Erythemal Action Spectrum. It includes a diffuser which provides good cosine response and multiple hard-oxide coatings that ensure that the interference filter provides the required spectral response. Each sensor is calibrated against a Yankee Environmental Systems Ultraviolet Pyranometer Model UVB-1 in natural, summer daylight. The unit's measurements are displayed in MED units (1 MED = 210 Jm^{-2}) at 1-minute intervals. These were converted into MED per 30 minutes or per 1 hour to match the SAWS biometer recording interval based on the measurement periods outlined in Table 1.

Table 1. Dates and times of 1-hour and 30-minute measurements periods as determined by the SAWS UV biometer measurement periods.

	Start date	Start time	End date	End time
1-hr interval	1-11-2014	24:00	30-11-2014	24:00
30-min interval	1-12-2014	1:00	5-12-2014	10:30
1-hr interval	5-12-2014	11:00	12-01-2015	8:00
30-minute interval	13-01-2015	8:30	31-01-2015	24:00

Data from the two streams of the SAWS and Davis instruments were compared, based on identical measurement periods and for the same durations, using linear regression. Upon observation of this initial result, it became apparent that SZA may be an important influencing factor for differences in instrument sensitivity. Hence, data were compared by SZA in three bands from small to large SZA: <35° (sun high in the sky); <70° and >35°; and < 105° and > 70° (sun low in the sky). SZA data was obtained from the Davis instrument. Linear regression was applied to determine for which SZA band correlation between the two instruments was the strongest. Analyses were carried out in Microsoft Excel 2013 and spearman correlation tests were made using STATA IC 13.1. During the analyses, notes were made about checks and challenges when making inter-instrument comparisons and these results are also presented.

3. Results and discussion

A total of 2 416 data points from each instrument were included in this analysis of three months' data. Careful procedures were executed to ensure that the identical measurement period and duration were matched for both data streams. All units are in MED/30 min or MED/hour.

3.1 All data together for both instruments

Figure 1 depicts the correlation between all data points for the SAWS and Davis instruments for all matching time periods. A good fit was evident with tighter correlation at lower MED values and more scatter with increasing MED values. At this early stage of analysis it was evident that the fit was not perfectly linear; there was a slight bowing in the trend line, suggesting that correlation between the two instruments' data points may vary by some external factor. Since SZA is the most obvious factor changing in a consistent manner based on the movement of the sun and thereby influencing solar UVR levels, this was identified as the factor for further analysis. Other factors such as cloud and aerosols usually cause erratic changes in solar UVR levels.

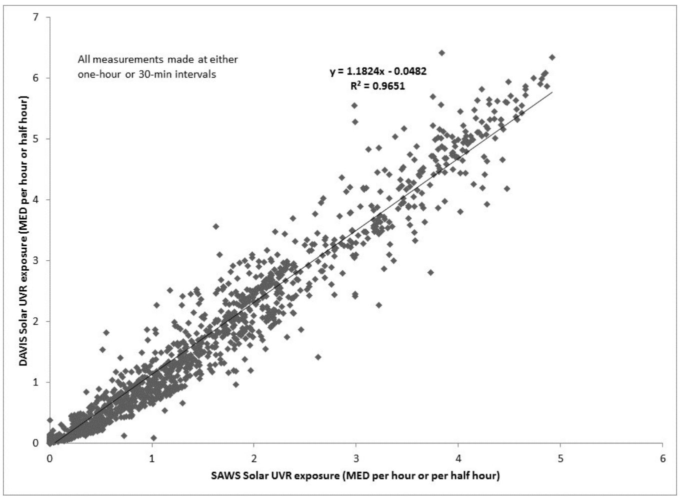

Figure 1. Correlation between SAWS and Davis data for all data points.

The Davis values were calculated as a percentage of the SAWS values and a mean of 107.12%, with a range of 10.75%-613.44% was found. Therefore, it seemed that the Davis instrument over-estimated solar UVR levels as measured by the SAWS instrument by, on average, 7%. The Spearman correlation test results for the Davis versus SAWS data returned ρ = 0.9694 (p<0.001).

3.2 Differences in measurement intervals

Before focussing on analyses using SZA, we considered the challenges of working with data derived from different measurement periods (i.e. measurement intervals set to 30 minutes versus 60 minutes). Figure 2 illustrates the challenges of trying to plot a time series using data from different measurement periods.

In general, there are more data points for the 30-minute measurement periods (two per hour) and MED values are half that of the 1-hourly measurements, as one would expect. A logical solution to this problem would be to merge MED values for 30-minute periods to create a 1-hour MED value instead and then be able to make comparisons across the whole measurement campaign. The disadvantage of doing so is that the finer resolution changes in solar UVR captured by the 30-minute measurements are then lost.

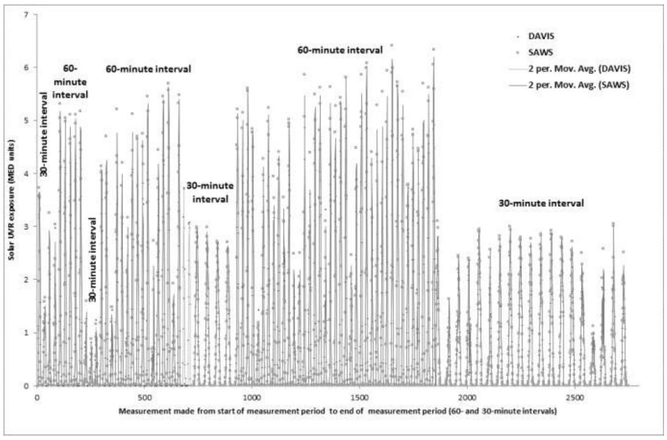

Figure 2. Quasi-time series plot to show changes in measurement intervals from 30- to 60-minute intervals during the measurement campaign driven by the changes made to the SAWS instrument measurement interval and with the Davis instrument data calculated to match the SAWS measurement interval.

3.3 Hourly data by SZA

The data sets were then split into hourly and half-hourly data sets to further investigate the role of SZA in the correlation coefficients of the two data sets. In so doing, one can see that the strength of the correlation is slightly stronger when the sun is low in the sky (large SZA) compared to when the sun is high in the sky (small SZA).

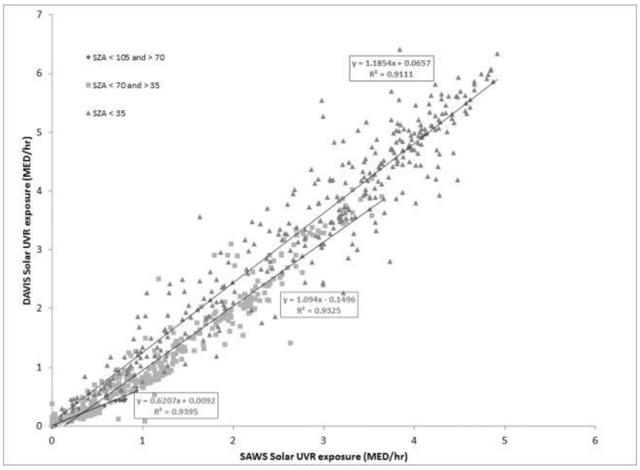

Figure 3. Correlation between SAWS data and Davis – hourly interval data only – by SZA band.

This may partly be explained by the location of the Davis UVR sensor on the meteorological station (Figure 4). It may be partially obscured by the rain gauge and by the pole on which the station is mounted, however, this needs further investigation as well as in relation to location of the sun's direct rays. The SAWS biometer sits on an unobscured tray and can scan the whole sky all day (Figure 5).

Figure 4. Location of the DAVIS UVR sensor (white dome in the centre of a black housing with small black fins on its rim indicated by the black arrow) on the DAVIS instrument in relation to surrounding physical obstructions.

Figure 5. Location of the SAWS biometer on the roof of SAWS Head Office in Pretoria.

3.4 Half-hourly data by SZA

A similar pattern of strength in correlation by SZA using the half-hourly data was found. R-squared values were highest for SZA <70° and > 35°, so roughly when the sun is midway between the horizon and directly above. While still a fair correlation, the lowest r-squared value was for when the sun was highest in the sky; the same finding as for the hourly readings in Figure 3. A possible reason for there not being a stronger correlation would be an error in the cosine response of the Davis UVR sensor which is specified as accurate to +- 4%. Such sensors are also prone to changes in response with temperature, which would also tend to vary in a fashion well-correlated with SZA.

3.5 Checks and challenges

When making inter-comparisons of solar UVR readings from two different instruments, the first check was to consider the specifications of both instruments. Here, both instruments were measuring solar irradiance closely matched to the Erythemal Action Spectrum.

The second check was to scrutinise the measuring unit of both instruments. In our case, both instruments were providing output in MED units where MED was fortunately defined as 210 Jm^{-2} for both data sets. This may not have been the case, since MED is usually defined by skin phototype and, unlike SED (Standard Erythemal Dose) unit which is always 1 SED = 100 Jm^{-2}, 1 MED may range from 210 Jm^{-2} for skin phototype I (fair skin, light eyes and hair) to 510 Jm^{-2} for skin phototype IV (Fitzpatrick, 1986).

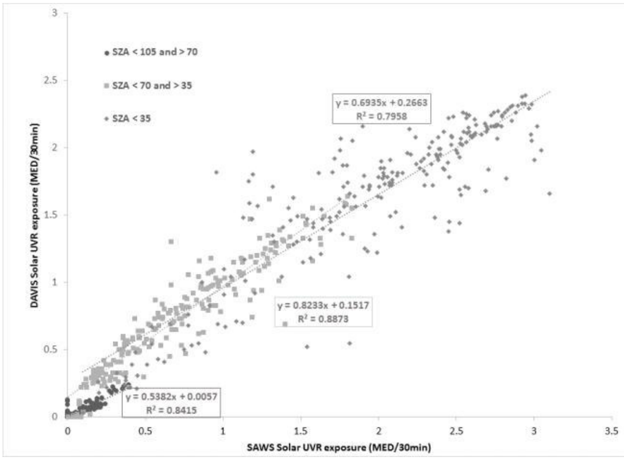

Figure 5. Correlation between SAWS data and DAVIS – half-hourly interval data only – by SZA band.

The first surprise arose when we plotted a time series of the raw data and noticed periods when data points were about half the amplitude of the highest data points. It became apparent that SAWS has changed the measuring interval and hence we needed to recalculate the Davis data accordingly.

The final investigation we made was a more detailed analysis of the influence of SZA on the relationship between the solar UVR data measured by the two instruments. We suspected that the two instruments' housing, location and orientation may have contributed to a non-perfect 1:1 relationship. Specifically, we were interested in the 'fins' arranged on the rim of the Davis instrument.

These fins are described by the manufacturer 'to aid in aligning the sensor with the sun's rays' (Davis, 2010). It therefore made sense to consider the role of SZA in the correlation of solar UVR measurements from the two instruments. Having found that the Davis instrument tended to overestimate UVR levels, and that the correlation between Davis and SAWS data was strongest for low-to-moderate solar UVR levels when the sun is not directly overhead, do not help to explain the influence of the fins. However, the relatively good r-squared values for all SZA do confirm that the Davis instrument measures solar UVR levels reasonably accurately when compared to the SAWS instrument (if we assume that the SAWS biometer is accurate).

4. Conclusions

Comparing solar UVR data measured by different instruments is possible, although careful consideration must be given to instrument set-up and location, measurement unit, recording interval, exposure calculations and the plotting of meaningful data on graphs.

5. Acknowledgements

The South African Weather Service is gratefully acknowledged for provision of solar UVR data. Patricia Albers (South African Medical Research Council) is thanked for assisting with drawing plots.

7. References

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