NOTES AND CORRESPONDENCE


Observations of shade-ring corrections for diffuse sky radiation measurements at the Dead Sea*

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SUMMARY

The shade-ring correction factor needed for measurements of diffuse irradiance at the Dead Sea averaged 1.41. Under normal near cloudless conditions, the anisotropy factor for sky radiation at the Dead Sea was in mid-winter 14% greater than that calculated on the basis of clear sky radiance distribution measured in central England, rising to a 28% excess in mid-summer. The relative strength of the circumsolar radiance calculated from the Dead Sea measurements was 1.54 compared with the value of 1.10 found to fit the data from nine other stations. The calculated angular width of the circumsolar zone at the Dead Sea, 0.65 radians, was, however, similar to that derived from data at other stations. Two possible reasons for the high degree of anisotropy are discussed. The correction factor was not influenced by the degree of cloud cover until over half the sky was clouded. On the very infrequent occasions of completely overcast skies the shade-ring factor averaged 1.16, agreeing with the value calculated solely on the basis of the geometric view factor. The error in measurement of diffuse irradiance at the Dead Sea caused by uncertainties in the value of the shade-ring correction was less than 5%, smaller than the uncertainty in the basic reference method of measurement.

1. INTRODUCTION

Poor visibility, pale skies and the relatively low intensities of global radiation observed at the Dead Sea—the lowest point on the earth’s surface and one of the most arid—suggest that the diffuse component of solar radiation is greater than the low levels of cloud cover observed there would suggest.

Routine measurements of the diffuse component using a shade-ring to shield the pyranometer from direct solar radiation require a significant correction to allow for radiation from that part of the sky occluded by the shade-ring. As this includes much of the circumsolar region, which radiates more strongly than the rest of the sky, this correction factor is greater than the fraction of the sky shaded by the ring (Drummond 1956).

Steven and Unsworth (1980) derived the part of the shade-ring correction factor attributable to the anisotropy of sky radiation from standard distributions of clear sky radiation as measured in the English Midlands. Comparison with correction factors observed at 10 sites ranging from 68°N to 26°S showed good agreement, suggesting that the circumsolar region of the skies had the same relative strength—1.10—and angular width—0.60 radians—at the various sites (Steven 1984). Drummond’s observations at Pretoria differed somewhat from this general relationship, possibly because of the station’s high elevation or due to a different size distribution of the scattering aerosol.

In view of the high atmospheric pressure at the Dead Sea, averaging 106 kPa, and local observations indicating an unusually high proportion of large aerosols (Ganor, personal communication), in situ measurements of the shade-ring correction factor were deemed necessary. This note reports the results of a series of such observations.

2. THEORY

The shade-ring correction factor, defined as the ratio of the diffuse irradiance from the whole sky, $S_\alpha$, to that measured by a pyranometer with a shade-ring, $S'_\alpha$, comprises two components related by the expression

$$S_\alpha/S'_\alpha = k = 1/(1 - FQ).$$  \hspace{1cm} (1)

The geometric, seasonally changing factor $F$ depends on the shade-ring’s size and position in relation both to the pyranometer and to the sun and is expressed as the fraction of diffuse radiation

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that would be occluded by the shade-ring if the sky radiation was completely isotropic. It can be calculated using Drummond’s expression

\[ F = 2br^{-1} \pi^{-1} (\cos^3 \delta) f' \]  

(2)

where \( f' = t_0 \sin \lambda \sin \delta + \sin t_0 \cos \lambda \cos \delta \), and \( b = \) ring width, \( r = \) ring radius, \( \delta = \) solar declination, \( \lambda = \) latitude and \( t_0 = \) hour angle (in radians from solar noon) of sunrise and sunset.

The second factor, \( Q \), represents the effect of anisotropy and is expressed as the ratio of the radiation occluded by the shade-ring—i.e. \( S_d - S_d' \)—to the calculated occluded value for an isotropic sky. Steven (1984) has shown that this ratio can be derived from the distribution of sky radiance and is simply related to three dimensionless parameters by the equation

\[ Q = 1 - C_a \xi_s + C_a / f' \]  

(3)

Details of the derivation of the first two parameters from sky radiance distributions will not be given here but it should be noted that the first parameter, \( C_a \), represents the relative strength of the circumsolar component of sky radiation and can be experimentally derived from the slope of the relationship of \( Q \) to \( 1/f' \). The second parameter, \( \xi_s \), represents the effective angular radius of the circumsolar zone in radians and is given by the value of \( 1/f' \) when \( Q = 1 \), i.e. when the sky radiates isotropically. The third geometric parameter, \( f' \), defined above, is a seasonally changing term describing the disposition of the sensor relative to the source.

3. METHODS

The observations reported were made during 1983 and 1984 near the efflux of the Quidron, an ephemeral stream reaching the Dead Sea on its north-west shore, at 31°40'N 35°27'E, 395 m below MSL.

Routine measurements of diffuse and global irradiance, \( S_d \) and \( K \downarrow \) respectively, were recorded using Kipp CM 11 pyranometers. The pyranometer used to measure \( S_d' \) was fitted with a shade-ring of the type and dimensions described by Drummond (1956), that is, a metal ring 51 mm wide with an inside diameter of 302 mm, painted black internally. Seasonal changes in solar declination were allowed for by adjusting the position of the shade-ring during weekly inspections.

The routine measurements of \( S_d' \) were compared with the true diffuse radiation from the whole sky, \( S_d \), measured by excluding the direct solar beam from irradiating a second pyranometer with a 10 cm diameter black disc held 100 cm from the radiometer, thus subtending a solid angle of 5°7'. The pyranometer used to measure \( S_d' \) was an Eppley Precision Spectral Pyranometer, which is maintained as a secondary standard. All three pyranometers were temperature-compensated instruments which meet the WMO specifications for a class 1 pyranometer (WMO 1981).

The disc-shaded measurements were made on six days selected to cover the full annual and diurnal range of solar positions and a range of synoptic situations.

The shade-ring correction was also determined on the few occasions when a complete cloud cover eliminated direct solar beam irradiance and \( S_d = K \downarrow \). Fourteen routine hourly measurements of \( K \downarrow \) and \( S_d' \) at Quidron were used either when local observations showed cloud cover was complete or when records from a recording rain gauge showed precipitation of 1 mm an hour or more.

4. RESULTS AND DISCUSSION

The average value of \( k \) derived from the 91 ratios of \( S_d / S_d' \) measured was 1.416, with a standard deviation of 0.084, individual values ranged from a maximum of 1.650 to a minimum of 1.164. Although the diurnal variation in \( k \) is small, as demonstrated by the low standard deviations for the individual days of measurement listed in Table 1, the differences in the average values of \( k \) on individual days are considerable.

(i) Clear sky conditions. For the five cloudless or near cloudless days of measurement at Quidron listed in Table 1 the anisotropy factor \( Q \) calculated from Eq. (1) averaged 2.93, ranging seasonally from a minimum of 1.414 to a maximum of 3.32. The seasonal component has been removed in Fig. 1 by plotting \( Q \) against \( 1/f' \). The line of best fit results in the following relationship, with a coefficient of determination \( r^2 = 0.96 \),

\[ Q = 1.560(1/f') + 0.014 \]  

(4)

which yields a relative strength for the circumsolar region of \( C_a = 1.56 \) and an angular width of the circumsolar region of \( \xi_s = 0.63 \) radians.
TABLE 1. Observed shade-ring correction and calculated anisotropy factors at Quidron

<table>
<thead>
<tr>
<th>Date and synoptic situation</th>
<th>Cloud cover (mean and standard deviation, oktas)</th>
<th>Measured shade-ring factor $k = S_0/S_0'$ (Mean and standard deviation)</th>
<th>Anisotropy factor $Q = (1 - 1/k)/F$</th>
<th>Geometric factor $F$</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 June 1983 High pressure over eastern Mediterranean, Red Sea trough, weak dry air flow from NE</td>
<td>0</td>
<td>1.424 ± 0.030</td>
<td>1.58</td>
<td>0.187</td>
</tr>
<tr>
<td>11 September 1983 Ridge from Turkey to Libya, strong flow from NW over Mediterranean</td>
<td>1.382 ± 0.022</td>
<td>1.41</td>
<td>1.93</td>
<td></td>
</tr>
<tr>
<td>18 December 1983 Ridge over Siberia, flow of cold, dry air from SW</td>
<td>4.8 ± 2.1</td>
<td>1.334 ± 0.079</td>
<td>3.15</td>
<td>0.079</td>
</tr>
<tr>
<td>8 January 1984 Ridge over Sinai causing flow from SW</td>
<td>1.5 ± 0.8</td>
<td>1.394 ± 0.061</td>
<td>3.32</td>
<td>0.084</td>
</tr>
<tr>
<td>3 April 1984 Displaced Red Sea trough, flow from Syrian desert to NE</td>
<td>1.7 ± 1.0</td>
<td>1.526 ± 0.068</td>
<td>1.77</td>
<td>0.193</td>
</tr>
<tr>
<td>11 December 1984 High pressure over eastern Mediterranean, air flow from NE</td>
<td>0</td>
<td>1.350 ± 0.026</td>
<td>3.13</td>
<td>0.083</td>
</tr>
</tbody>
</table>

The anisotropy at Quidron and the relative strength of the circumsolar radiation are considerably greater than at any of the ten stations whose data were analysed by Steven (1984). All but one of these data sets fitted the relationship $Q = 1.10(1/f^4) + 0.34$ derived from the sky radiance distribution measured under clear sky conditions in central England. The anomalous data

Figure 1. The relationship between the shade-ring anisotropy factor $Q$ and the geometric parameter $1/f^4$, calculated from clear day measurements at the Dead Sea (solid line and circles), from Steven's composite clear sky radiance measurements in central England (long dashes) and Drummond's measurements at Pretoria (short dashes). The star represents a clear day's measurements at Jerusalem.
set was from Pretoria, the site with the highest elevation, 1369 m above MSL, which fitted the relationship \( Q = 0.71(1/f') + 0.48 \), paradoxically implying weaker radiation from the circumsolar region.

The angular width of the circumsolar zone derived from the Quidron measurements, 0.63 radians, is essentially similar to the value given by Steven, 0.60, for central England which fitted the data from the other stations examined. The value of \( \xi^* \) for the high altitude station, 0.73, is also close to that for Quidron.

Two possible reasons for the high anisotropy of clear sky radiation at the Dead Sea, parametrized by the high relative strength of the circumsolar component, are the total size of the aerosol load and/or its size distribution.

The deep atmospheric column at the Dead Sea would be expected to increase Rayleigh scattering in proportion to the atmospheric pressure, i.e. by about 5%, and Mie scattering in proportion to the increase in aerosol loading. An increased loading of large aerosol could be caused by the combined effects of the surrounding deserts and salt spray from the Dead Sea. In this connection it may be noteworthy that Table 1 shows that the lowest anisotropy factor was observed when the trajectory of the air mass reaching the Dead Sea was over the Mediterranean Sea.

Some support for the view that the depth of the air column at the Dead Sea is associated with the high anisotropy is provided by the results of a clear day’s measurements of \( S_d \) and \( S_d' \) at Jerusalem (31°41'N 35°15'E, 789 m), 25 km NW of Quidron and on the western border of the Judean desert. The very low anisotropy value, \( Q = 1.073 \), shown in Fig. 1 is presumably explained by the 1185 m elevation difference between the two sites.

(ii) Overcast conditions. The extent to which differences in cloud cover at the Dead Sea affect the size of the shade-ring factor was investigated by grouping measurements of \( k \) according to the observed degree of cloud cover, \( c \), expressed in oktas. Figure 2 shows that a marked reduction occurred only when more than half the sky was covered by cloud.

On the few occasions when the sky was completely covered with cloud and \( S_d = K \downarrow \), \( k \) averaged 1.165 with a standard deviation of 0.083. A similar value of \( k \) for overcast conditions was obtained by extrapolating the relationship between \( k \) and cloud cover above 4 oktas to 8 oktas (Fig. 2). Both the measured and extrapolated value of \( k \) for overcast skies agreed with the calculated

![Figure 2. Measurements of shade-ring correction factor \( k \) grouped according to cloud cover \( c \) in oktas observed at the time of measurement.](image-url)
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TABLE 2. COMPONENTS OF INCIDENT SOLAR RADIATION AT QUIDRON, UNITS MJ m⁻² d⁻¹

<table>
<thead>
<tr>
<th>Month</th>
<th>Extra-terrestrial $K \downarrow\downarrow$</th>
<th>Global $K \downarrow$</th>
<th>Diffuse with shade-ring $S_\alpha$</th>
<th>Shade-ring correction factor $k$</th>
<th>Diffuse $S_e = S_\alpha \cdot k$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jan. 1984</td>
<td>20.0</td>
<td>10.3</td>
<td>3.6</td>
<td>1.37</td>
<td>4.9</td>
</tr>
<tr>
<td>Feb. 1984</td>
<td>25.0</td>
<td>15.4</td>
<td>3.9</td>
<td>1.40</td>
<td>5.4</td>
</tr>
<tr>
<td>Mar. 1983</td>
<td>31.0</td>
<td>17.2</td>
<td>5.7</td>
<td>1.50</td>
<td>8.6</td>
</tr>
<tr>
<td>Apr. 1983</td>
<td>36.9</td>
<td>20.7</td>
<td>6.6</td>
<td>1.47</td>
<td>9.7</td>
</tr>
<tr>
<td>May 1983</td>
<td>40.2</td>
<td>23.7</td>
<td>7.0</td>
<td>1.40</td>
<td>9.7</td>
</tr>
<tr>
<td>June 1983</td>
<td>41.2</td>
<td>27.1</td>
<td>6.8</td>
<td>1.35</td>
<td>9.2</td>
</tr>
<tr>
<td>July 1983</td>
<td>40.1</td>
<td>26.9</td>
<td>6.1</td>
<td>1.37</td>
<td>8.3</td>
</tr>
<tr>
<td>Aug. 1983</td>
<td>36.9</td>
<td>24.6</td>
<td>6.4</td>
<td>1.44</td>
<td>9.1</td>
</tr>
<tr>
<td>Sept. 1983</td>
<td>31.7</td>
<td>21.2</td>
<td>4.4</td>
<td>1.50</td>
<td>6.5</td>
</tr>
<tr>
<td>Oct. 1983</td>
<td>25.9</td>
<td>16.8</td>
<td>3.9</td>
<td>1.47</td>
<td>5.7</td>
</tr>
<tr>
<td>Nov. 1983</td>
<td>20.6</td>
<td>12.2</td>
<td>3.3</td>
<td>1.40</td>
<td>4.6</td>
</tr>
<tr>
<td>Dec. 1983</td>
<td>17.9</td>
<td>9.9</td>
<td>3.3</td>
<td>1.35</td>
<td>4.5</td>
</tr>
<tr>
<td>Annual total</td>
<td>GJ m⁻²</td>
<td>11.20</td>
<td>7.03</td>
<td>1.85</td>
<td>2.63</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.418</td>
</tr>
</tbody>
</table>

Thus, the few measurements under cloud-covered skies agree with the findings in southern England that sky radiation from the circumsolar region is the same as that for the rest of an overcast sky (Painter 1981; Steven 1984).

(iii) **Diffuse radiation measurements.** The results of the first year's measurements of $S_\alpha$ at Quidron are presented in Table 2. These have been corrected with a shade-ring factor estimated with Eq. (1) using values of $Q$ calculated from Eq. (4). The assumption of clear sky anisotropy has been justified by the fact that long-term average values for cloud cover observed at Kallia, 10 km north of Quidron, never exceeded 4 oktas even during mid-winter (Neumann 1958). The annual mean of the calculated values of $k$ given in Table 2 is the same as the mean of the 91 measured values, giving confidence that the method adopted to derive estimates of $k$ is accurate for use with mean daily values.

The annual total diffuse irradiance—2.63 GJ m⁻²—is 0.39 of the measured global irradiance and the fraction $S_\alpha/K \downarrow$ varies seasonally from a maximum of 0.50 in March to minima of 0.31 in July and September. Expressed as a fraction of the total shortwave irradiance absorbed and scattered by the atmosphere, i.e. $S_\alpha/K \downarrow - (K \downarrow - S_\alpha)$, where $K \downarrow$ is the global radiation at the top of the earth's atmosphere, 0.39 of the annual total reaches the surface at the Dead Sea in the form of forward-scattered radiation. There is some seasonal variation in this fraction with the minimum occurring in January and the maximum in August, the month with the highest atmospheric transmissivity.

For individual days the non-seasonal, day-to-day variation in $k$ appears to be small from the small scatter in the relationship between $Q$ and $1/f'$ (Fig. 1) and the agreement in values measured around the winter solstice (Table 1).

Within individual cloudless days the variation in $k$ is less than 5%, and is smaller than the uncertainty in the basic reference method for measuring diffuse sky irradiance (Bruce Baker 1984).

The results of these measurements confirm the view that diffuse sky irradiance is a major element in the solar radiation balance both at the surface and in the atmosphere of the Dead Sea and demonstrate that its accurate measurement requires the use of a locally verified shade-ring correction factor.

**Acknowledgments**

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REFERENCES


Steven, M. D. 1984 The anisotropy of diffuse solar radiation determined from shade-ring measurements. ibid., 110, 261–270