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PROJECT F - SOLAR RADIATION DATA

EC SOLAR ENERGY R & D PROGRAMME

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INVESTIGATION OF THE ACCURACY OF SHADING RING CORRECTIONS APPLIED IN THE MEASUREMENT OF DIFFUSE SOLAR RADIATION

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FINAL REPORT

SUMMARY

The Diffuse Sky Radiation as measured with a pyranometer and shading ring must be corrected to compensate for sky radiation cut off by the ring. This correction is generally computed on the basis of the geometric area of the sky cut off and assuming isotropic sky.

This assumption results in values of D_R which differ from the true value D_c by a factor "k" = D_c/D_R.

The frequency distribution of k for the 2-year period was:

k =	0.9	1.0	1.1	1.2	1.3	1.4	1.5
frequency % =	1.58	51.45	32.56	12.30	1.84	0.22	0.05

There was no significant dependence of k on Solar Elevation and only a very slight dependence on Solar Declination (d).

The most significant variations of k are associated with D_R/G and the following equation was found to fit the data closely:

$$k = 1.1578 - 0.1548(D_R/G)^3 - 0.000143d$$

When the observed data are adjusted by applying the factor k as derived from this formula 83.47% of the data are brought within $\pm$ 5% of the true value and 96.48% of the data are correct within $\pm$ 10%.

INVESTIGATION OF THE ACCURACY OF SHADING RING CORRECTIONS APPLIED IN THE MEASUREMENT OF DIFFUSE SOLAR RADIATION

1. Project description

1.1. Introduction

The measurement of Diffuse Sky Radiation is most frequently done by means of a pyranometer combined with shading ring to shield the pyranometer from the direct solar beam. The ring, which casts a shadow of projected width somewhat larger than the pyranometer sensor is mounted on a polar axis so as to obscure the entire diurnal path of the sun. Adjustments are necessary every few days to allow for changing solar declination. Ring designs are discussed fully by Blackwell [1] and Drummond [2].

The shade ring obscures not only the sun but also a considerable area of the sky, so the measured values must be corrected to compensate for the sky radiation cut off by the ring. This correction is generally computed on the basis of the geometric area of sky obscured by the ring and assuming that the sky irradiance is isotropic even though the sky is often very anisotropic. It is now generally accepted that diffuse irradiance obtained with a shading ring and corrected by the geometric correction, assuming isotropic sky, results in values which are considerably underestimated especially in clear or only partly cloudy skies. Drummond [2] made comparisons in South Africa between diffuse irradiances obtained with a ring and a disc and found that the measurements made with the ring and corrected by the geometric factor, assuming isotropic conditions, were, on average, underestimated by 7%, with mainly clear skies, and about 5% in partly cloudy skies.

The purpose of this project is to assess the error involved in the isotropic-geometric corrections and to find a method of obtaining the additional correction to be applied to the diffuse ring data to bring them nearer the true data in middle latitude conditions.

1.2. Instrumentation and measurement

At Valentia Observatory a pyrheliometer on solar tracker has been measuring the Direct Sun radiation at Normal Incidence (I) since November 1978. The Global Solar radiation on a horizontal surface (G) has also been measured.

The combination of Direct Sun measurement (I) and the Global measurement (G) provides the most accurate measurement of the Diffuse Sky radiation on a horizontal surface from the relation:

$$D_c = G - I\mathrm{Sin}E \qquad (1)$$

where E is the solar elevation.

The Diffuse Sky radiation on a horizontal surface was also measured by the shading ring method and the geometric-isotropic correction applied, giving D_R.

1.2.1. Instruments used

The instruments in use during the 2-year period for the measurement of Direct Sun, Global and Diffuse radiation were as follows:

	Sensor	Integrator
Direct Sun	Eppley NIP Type E6	Eppley 411-5880
Global	Kipp and Zonen Type G2	Lintronic 717A
Diffuse	Kipp and Zonen Type G18	Lintronic 484B

Shading Ring width (b) = 50mm Radius (r) 155mm

b/r = 0.32

1.2.2. Diffuse Sky Geometric-isotropic Correction Factors

The factors used to correct the measured diffuse irradiance data for the geometric area of sky cut off by the ring (assuming isotropic sky) were as shown in Table 1.

Table 1. Geometric-isotropic Correction Factors

Period	Factor	Period	Factor
Jan 1 - 9 Dec 3 - 31	1.05	Jan 10 - 21 Nov 19 - Dec 2	1.06
Jan 22 - 30 Nov 11 - 18	1.07	Jan 31 - Feb 6 Nov 5 - 10	1.08
Feb 7 - 11 Oct 30 - Nov 4	1.09	Feb 12 - 15 Oct 26 - 29	1.10
Feb 16 - 21 Oct 20 - 25	1.11	Feb 22 - 27 Oct 14 - 19	1.12
Feb 28 - Mar 3 Oct 8 - 13	1.13	Mar 4 - 11 Oct 1 - 7	1.14
Mar 12 - 21 Sept21 - 30	1.15	Mar 22 - 30 Sept 11 - 20	1.16
Mar 31 - Apr 12 Aug 30 - Sept10	1.17	Apr 13 - 26 Aug 16 - 29	1.18
Apr 27 - May 9 Aug 2 - 15	1.19	May 10 - 26 July 17 - Aug 1	1.20
May 27 - July 16	1.21		

The correction factors shown in Table 1 above, correspond to the dimensions of the Valentia ring. They are based on the method recommended by Blackwell [1] and are in good agreement with those recommended by Drummond [2].

1.3. Analysis procedure

As stated above the most accurate value of the Diffuse Sky irradiance is obtained from the combination of Direct Sun and Global measurements as given in equation (1).

If "k" is the factor required to reduce the D_R data to the true data D_C then

$$D_C = G - ISinE = kD_R \ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The factor $k = \frac{G - ISinE}{D_R}$ was computed for each hour of the 2-year period 1979/80 and analysed.

In the analysis the following data were rejected:

(1) All data when the solar elevation E was less than 10^o
(2) All data when G was less than $20J/cm^2$. In practice all data are rounded off to the nearest 1 J/cm^2 and moreover the accuracy of measurement in any element can only be relied upon to within $\pm$ 5%. Thus the smaller values could result in unreliable values of k.

2. Results obtained

2.1. Frequency distribution of "k"

The overall mean value was found to be k = 1.062. The frequency distribution of k values for the 2-year period was as follows:

	k = 0.9	1.0	1.1	1.2	1.3	1.4	1.5
Frequency	% = 1.58	51.45	32.56	12.30	1.84	0.22	0.05

This means that on average the diffuse radiation data as generally derived from the shading ring plus geometric correction, based on isotropic sky, are underestimated by 6.2%; 30% of the hourly values are underestimated by more than 10%; 14% of the hourly values are underestimated by more than 15% and 6.5% of the hourly values are underestimated by more than 20%.

2.1.1. Seasonal variation

The frequency distribution of k is very similar for the different seasons of the year. To investigate this seasonal aspect the data were grouped in 10 ranges of solar declination each range being a declination band as shown in Table 2.

Table 2 - Band-Widths of Solar Declination (d)

	Winter			Equinox				Summer		
Range	1	2	3	4	5	6	7	8	9	10
d	-23.4 to -20	-19.9 to -15.0	-14.9 to -10.0	-9.9 to -5.0	-4.9 to 0	+0.1 to +5.0	+5.1 to +10.0	+10.1 to +15	+15.1 to +20	+20.1 to +23.4

The percentage distribution of k for each range of solar declination (d) is given in Table 3.

Table 3 Percentage Frequency distribution of k for various ranges of d

Range \ k	0.9	1.0	1.1	1.2	1.3	1.4	1.5	Number of Hourly Values
1	3.05	56.85	29.95	8.38	1.52	0.25	0.00	394
2	0.87	56.56	28.86	12.24	1.17	0.30	0.00	343
3	2.91	51.13	26.86	15.86	2.59	0.65	0.00	309
4	3.58	45.78	34.27	14.07	2.30	0.00	0.00	391
5	2.93	47.48	30.50	16.45	2.65	0.00	0.00	377
6	2.60	47.29	29.28	16.49	4.34	0.00	0.00	461
7	0.92	44.67	34.74	17.10	2.57	0.00	0.00	544
8	0.78	45.95	36.45	14.33	2.18	0.31	0.00	642
9	1.33	56.85	30.81	10.79	0.22	0.00	0.00	899
10	0.68	54.08	34.79	8.40	1.43	0.00	0.00	1607
Year	1.58	51.45	32.56	12.30	1.84	0.22	0.05	5967

Grouping the annual data into three seasons (Winter, Equinox and Summer) of approximately 4 months each as shown in Table 2 the frequency distribution for each season becomes

Winter (d below -10^o)	k	0.9	1.0	1.1	1.2	1.3	1.4	
		2.29	55.07	28.68	11.85	1.72	0.38	
Equinox (d between -10^o and $+10^o$)	k	0.9	1.0	1.1	1.2	1.3	1.4	1.5
		2.37	46.19	32.32	16.13	2.99	0.00	0.00
Summer (d greater than $+10^o$)	k	0.9	1.0	1.1	1.2	1.3	1.4	1.5
		0.89	53.21	33.99	10.29	1.24	0.29	0.09

The distribution curves for each of the three seasons are shown with the annual distribution curves in Figs 1-3. The only points of note are

(1) The highest percentage frequency of k = 1.0 occurs in winter and the lowest at the equinox.
(2) A tendency for a higher percentage frequency of k = 1.2 or more during the equinoctial period.

These factors can probably be attributed to the sky conditions which generally prevail during these seasons, in the middle latitude of Valentia. Overcast skies are more prevalent in the winter while settled anticyclonic conditions tend to occur in late spring and in early autumn.

2.2. Variation with Solar Elevation (E)

The data were assembled according to solar elevation (E) for ranges of 5^o and the mean value of k found for each range as follows:

Table 4 Mean value of k for various ranges of Solar Elevation

E^o	10 to 14.9	15 to 19.9	20 to 24.9	25 to 29.9	30 to 34.9	35 to 39.9	40 to 44.9	45 to 49.9	50 to 54.9	55 to 59.9	Full Year
k	1.057	1.054	1.054	1.060	1.067	1.063	1.069	1.073	1.070	1.067	1.062

The data above are shown graphically in Fig. 4.

There seems to be a tendency towards higher values with increasing elevation. However the overall range from 1.054 to 1.073, representing only ± 1% about the mean value could hardly be considered as a significant dependence of "k" on solar elevation.

2.3. Variation of k with Solar Declination (d)

In section 2.1.1. above it was shown how the data were assembled into solar declination bands to examine the frequency distribution on a seasonal basis.

For each range of solar declination (See Table 2 above) the mean value of k was computed. These were as follows:

Table 5 Mean value of k for each range of Solar Declination

Range	1	2	3	4	5	6	7	8	9	10
k	1.052	1.057	1.062	1.064	1.065	1.068	1.077	1.072	1.053	1.059
	Winter k = 1.057			Equinox k = 1.069				Summer k = 1.060		

It would appear therefore that the contribution of solar declination to the variation of k is limited to about ± 1% with the higher values occurring in the equinoctial period and the lower values during the winter period.

2.4. Variation of k with D_R/G

The values of D_R/G were computed for each hour of the 2-year period and the corresponding values of k assembled in band widths of 0.1 for D_R/G. The mean value of k for each band width is shown in Table 6.

Table 6 Mean values of k for band-widths of DR/G

D_R/G	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
k	1.156	1.138	1.147	1.136	1.117	1.104	1.081	1.051	0.997

The data are shown graphically in fig. 5. These values would indicate that the value of D_R/G was the most important factor in the variation of k values and show a definite trend of increasing k with decreasing values of D_R/G while the diffuse radiation as at present derived would be accurate when the skies were overcast or almost completely clouded.

In view of the obvious importance of D_R/G in the determination of the k values an effort was made to fit an equation to represent the variation of k with D_R/G.. The solar declination (d) was also included as a parameter even though, as stated in para 2.3. above, its contribution was small.

The following equation was found to fit the data very closely:

$$k = 1.1578 - 0.1548(D_R/G)^3 - 0.000143d \quad \text{.............(3)}$$

Computing k for each value of D_R/G in Table 6 above gives the following results (ignoring the declination contribution which is negligible).

Table 7 Values of k computed from formula (3)

D_R/G	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0
k	1.157	1.154	1.148	1.138	1.124	1.105	1.079	1.045	1.003

These values are also plotted in fig. 5 which shows the very good fit of the equation to the observed values.

The values of k given in Table 7 provide factors for correcting the hourly values of diffuse radiation as measured with the ring and to which the geometric ring corrections (assuming isotropic sky) have already been applied. When the hourly data are so adjusted and, the adjusted k value (say k1) computed, the frequency distribution now becomes:

k1 =	0.8	0.9	1.0	1.1	1.2	1.3	1.4
Frequency % =	0.27	8.23	83.47	7.53	0.40	0.08	0.02

This distribution is shown graphically in fig. 6.

It can be seen that by adjusting the data by means of the factor "k" found from equation (3) the accuracy is improved to the extent that 83.47% of the data are correct to within ± 5% of the true value and 96.48% of the data are correct to within ± 10%.

3. Conclusion

Hourly values of diffuse solar radiation may be determined with acceptable accuracy with pyranometer plus shading ring provided the following procedure is followed:

(1) The values as measured should firstly be corrected for the sky radiation cut off by the ring. This is done on a purely geometric basis and assuming isotropic sky (Blackwell [1] or Drummond [2]).

(2) The data resulting from (1) should then be corrected by application of a further factor k as determined from equation (3) or interpolated from the values given in Table 7 since D_R/G is readily available.

Strictly speaking equation (3) for the correction factors applies to the shading ring in use at Valentia. Other stations may use a shading ring of different dimensions i.e. different b/r ratio. It still remains to be seen how the equation and the resultant k factors may be influenced by variations in the b/r ratio of the shading ring.

REFERENCES

1. M.J. Blackwell, "Five years continuous recording of total and diffuse solar radiation at Kew Observatory", Air Ministry Meteorol. Res. Comm., London, M.R.P. 895 (1954).

2. A. J. Drummond, "On the measurement of sky radiation", Arch. Meteorol. Geophys. Biokilm. Ser. B 9, 124-148 (1956).

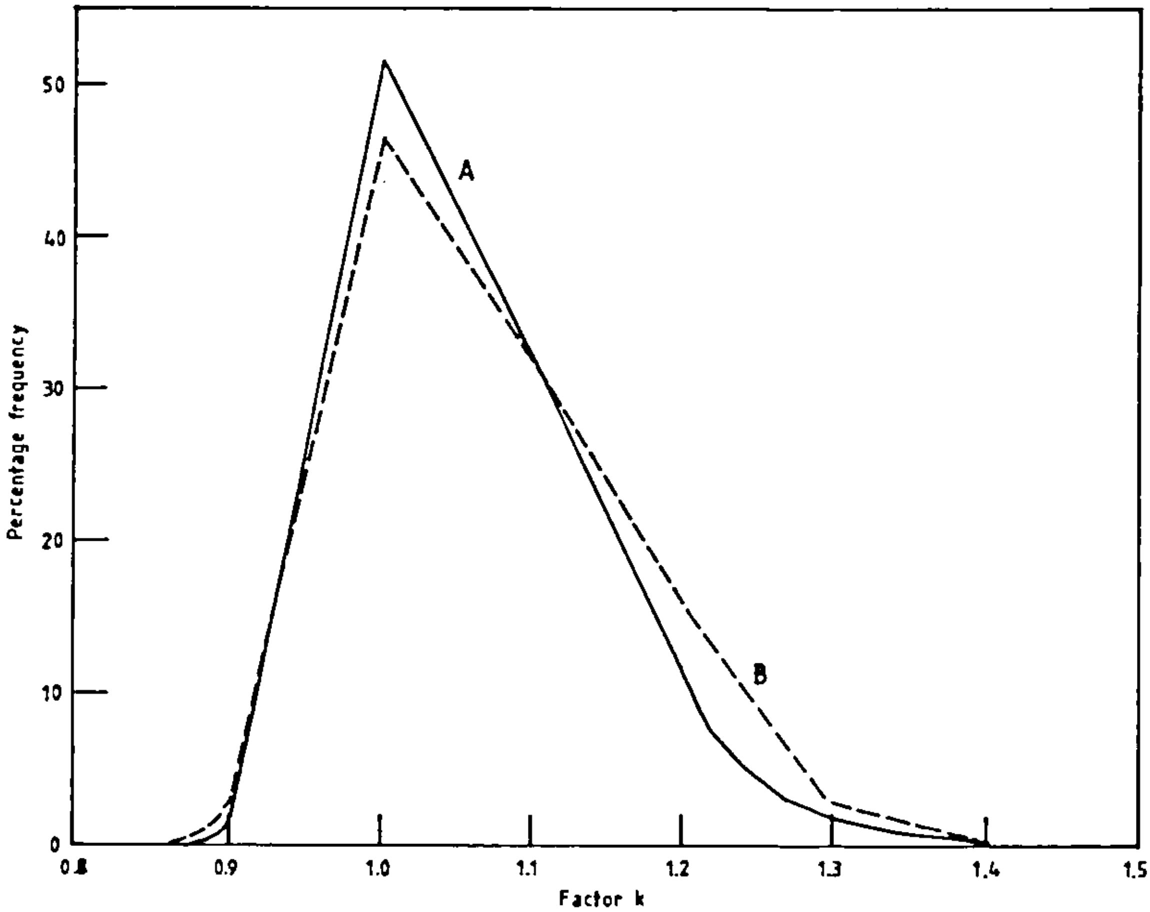

Fig. 1. Frequency distribution of k for (A) full year and (B) equinox.

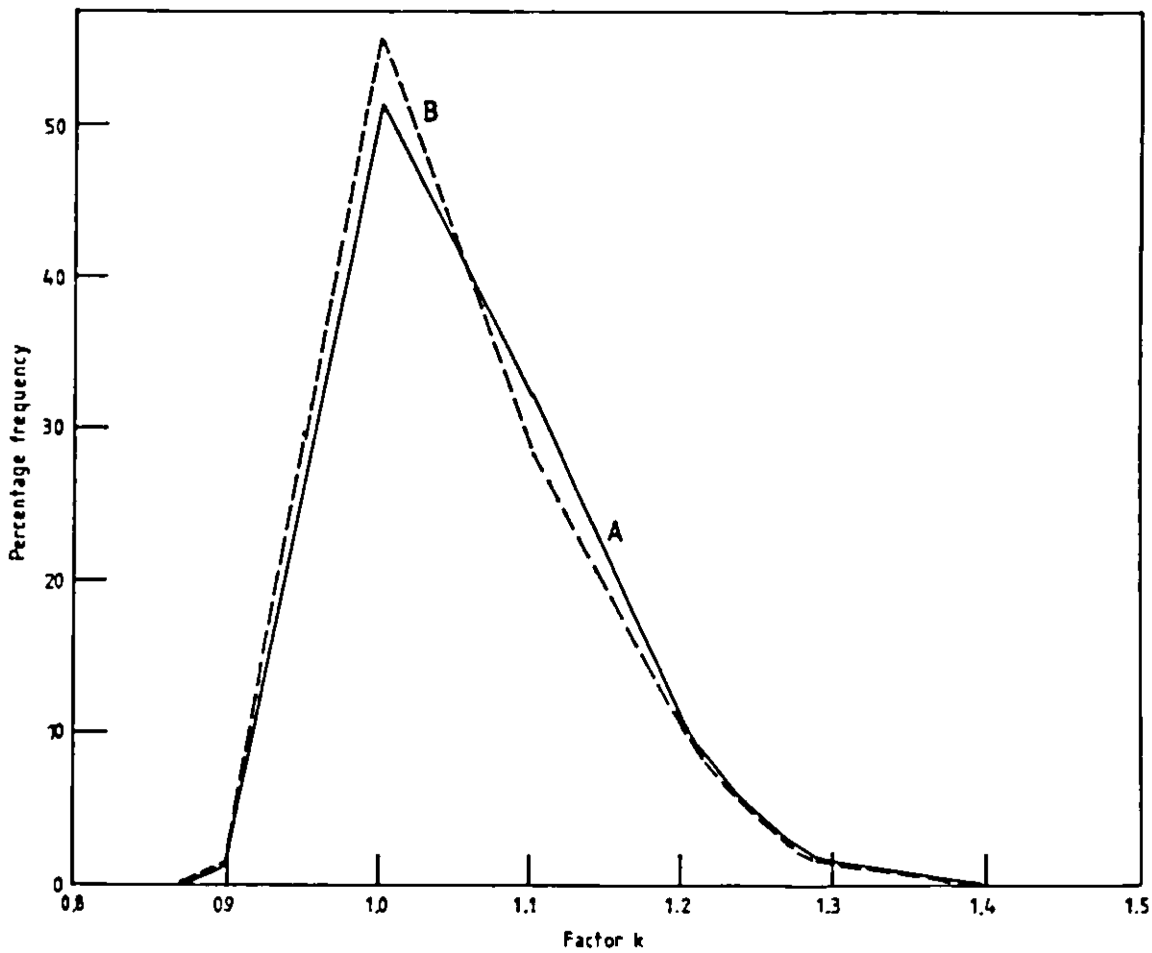

Fig. 2. Frequency distribution of k for (A) full year and (B) winter.

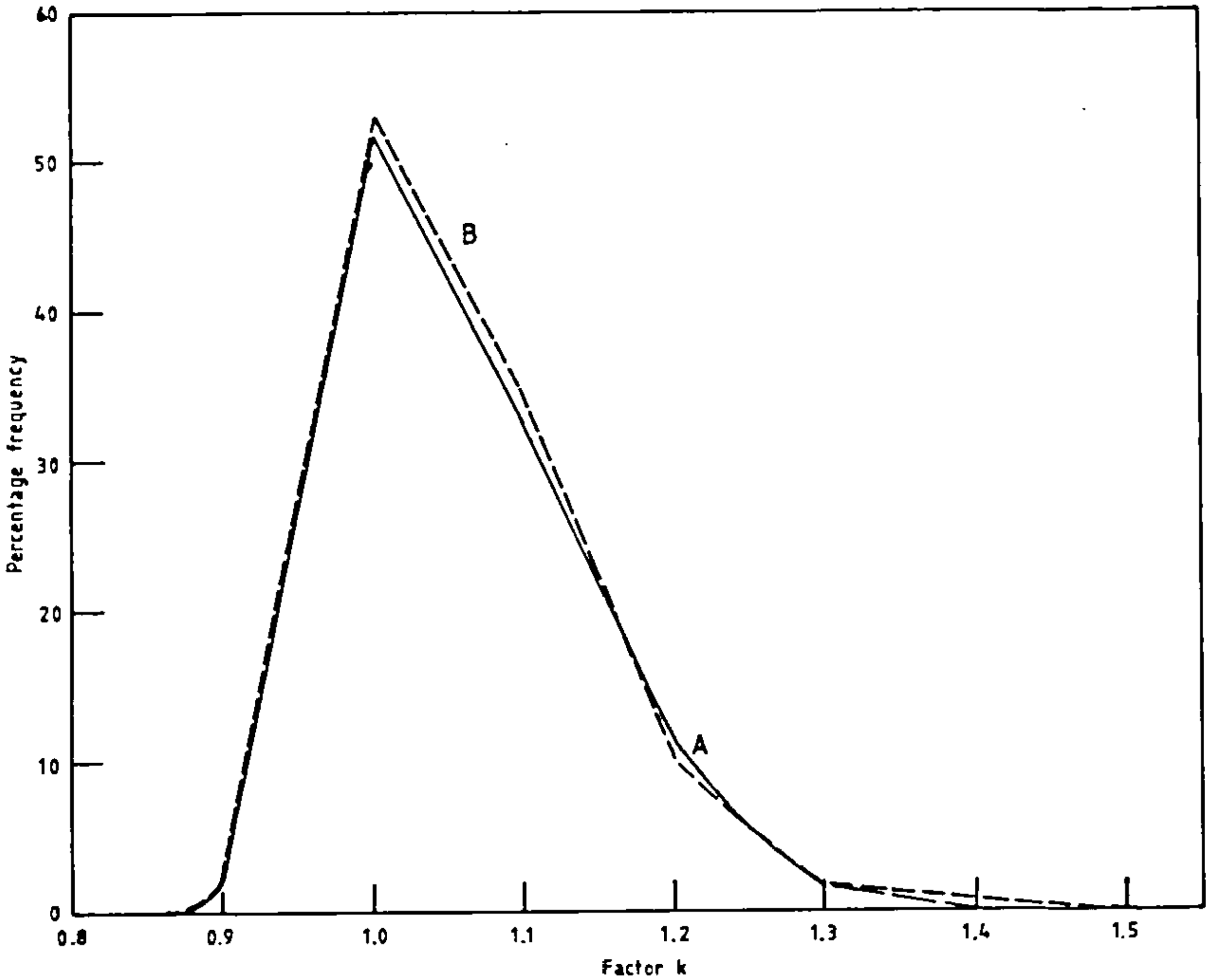

Fig. 3. Frequency distribution of k for -(A) full year and (B) summer

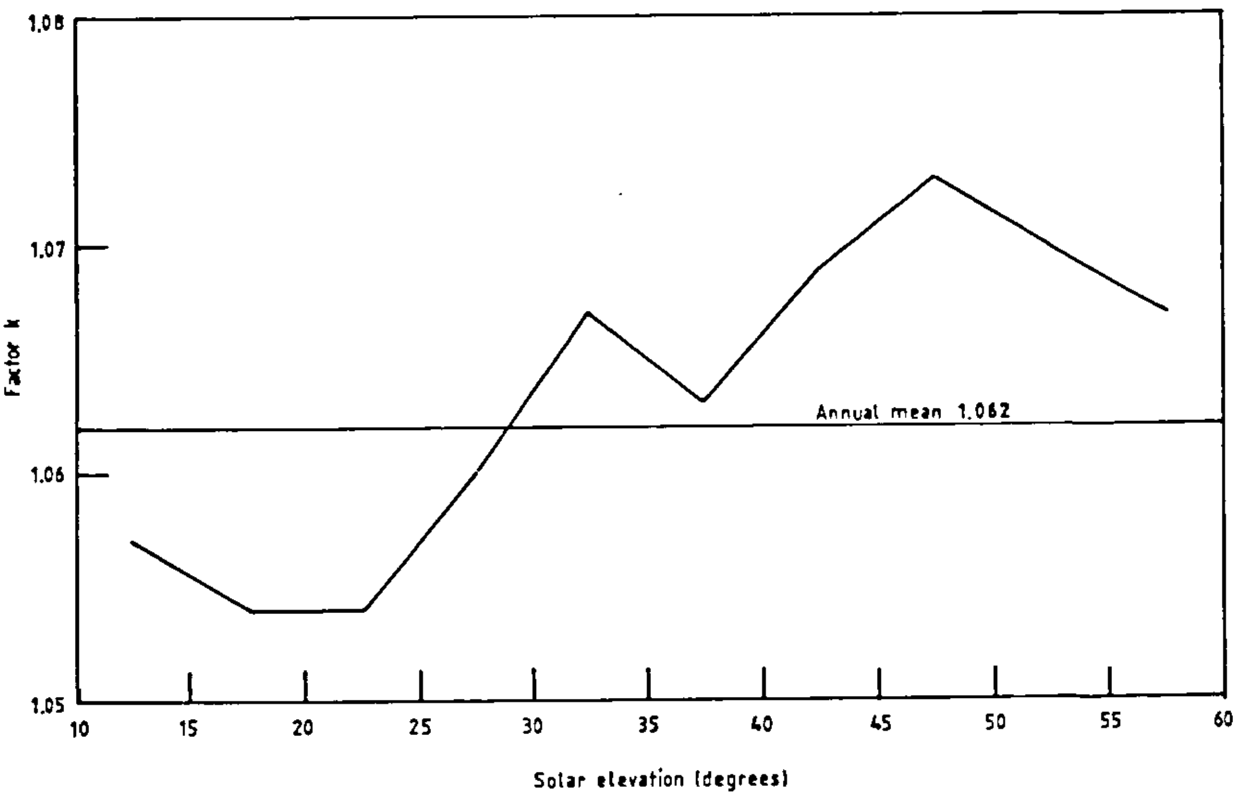

Fig. 4. Variation of k with Solar elevation

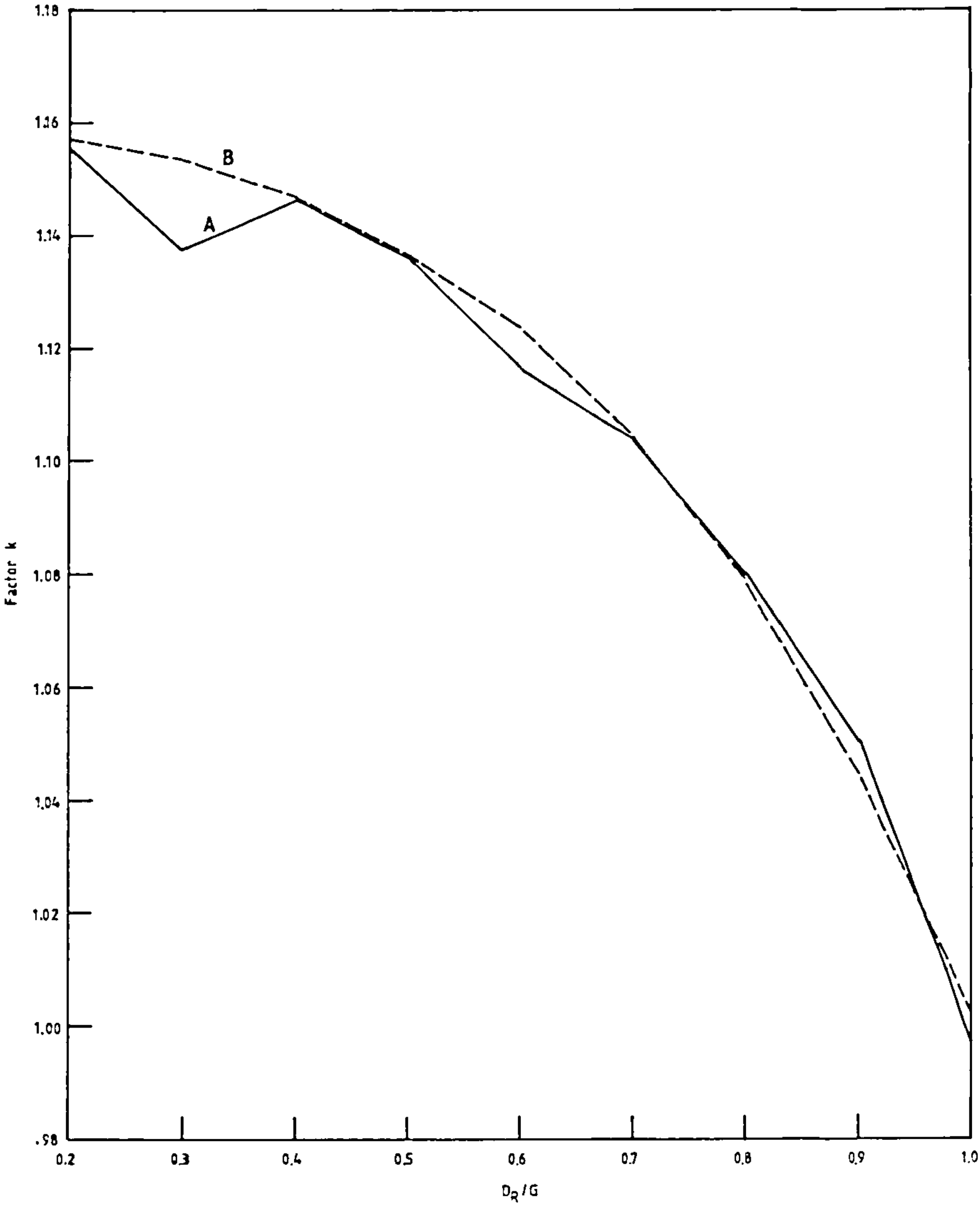

Fig. 5. Variation of k with D_R/G (A) observed values and (B) computed from formula 3.

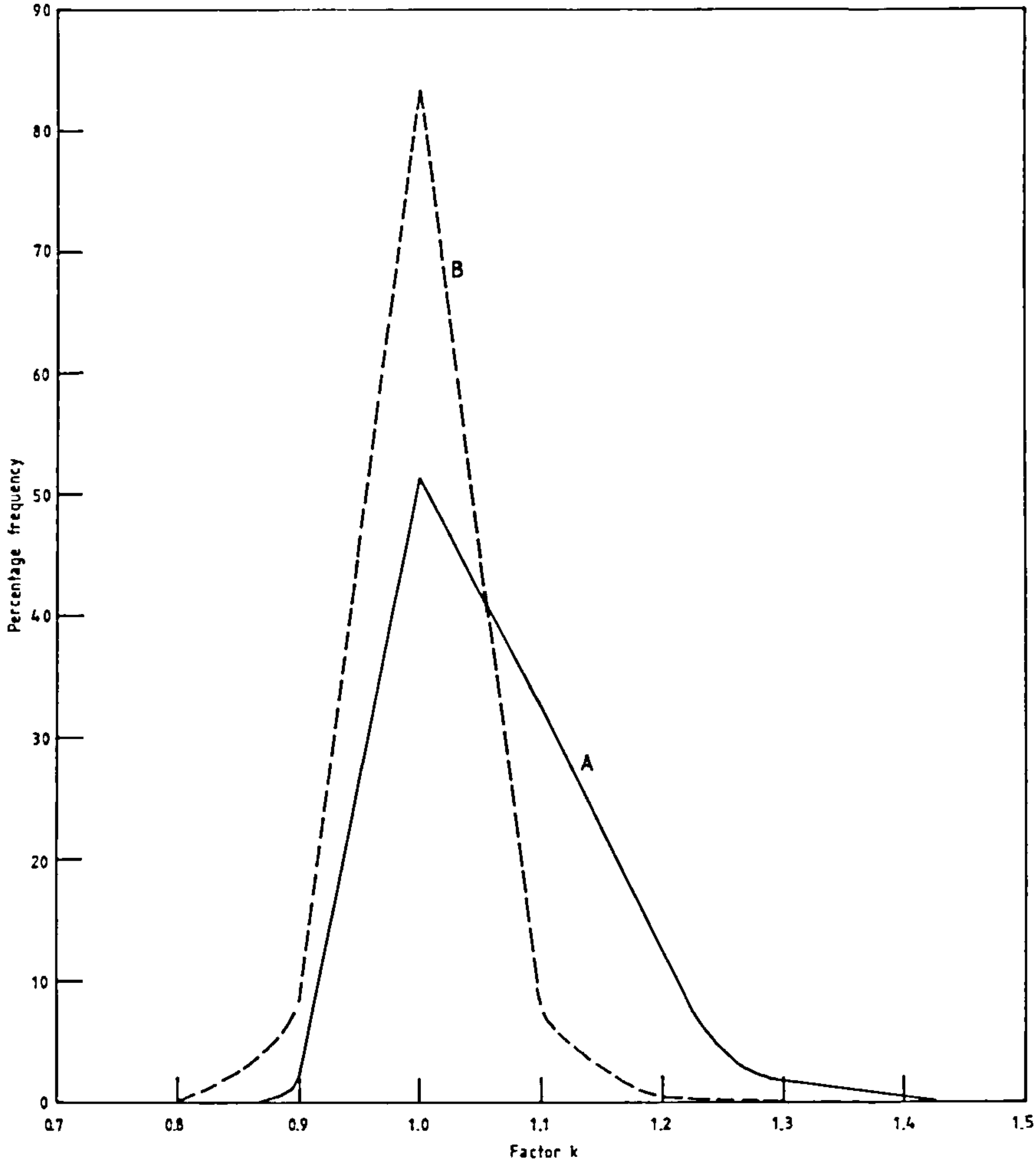

Fig. 6. Frequency distribution of k for (A) original data and (B) data after adjustment by means of equation 3.