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3 October 1974

551.510.42 : 551.521.31

Attenuation of total solar radiation by aerosol over Britain and the Atlantic Ocean

By M. H. Unsworth and J. L. Monteith

In a recent note, Collier and Lockwood (1974) compared measurements of total solar radiation on cloudless days at an inland site in England with radiation calculated from empirical expressions derived from (i) data from weather ships in the eastern Atlantic (Lumb 1964) and (ii) measurements of radiation and turbidity in central England (Unsworth and Monteith 1972). Collier and Lockwood concluded that radiation received inland under cloudless skies was only about 60% of that received over the sea. As this figure is inconsistent with the whole literature of radiation climatology in Britain, we believe there must be large errors both in the measurements they recorded and in estimates they derived from independent empirical relationships.

Collier and Lockwood tabulated hourly mean values of total solar radiation S_t for three cloudless days (20 August 1971, 14 October 1971 and 21 January 1972) and they plotted the dependence of S_t on solar elevation θ for these and other days. Hourly means of S_t are recorded by the Meteorological Office and other establishments for a number of sites, and comparison shows clearly that for given values of θ, under cloudless skies, Collier and Lockwood's values are 30–40% lower than those recorded elsewhere in Britain. As an example, Collier and Lockwood's measurements for 20 August 1971 are compared in Table 1 with hourly fluxes of radiation recorded on the same day at Eskdalemuir (55·2°N, 3·1°W), about 250km NNW of Leeds. Cloud at Sutton Bonington precludes comparison with our own record on this occasion. The authors claim that radiation records from Sutton Bonington were generally consistent with their own. This is wrong: records from Sutton Bonington agree well with those from Meteorological Office sites. There appears to be a consistent error of about −33% either in the calibration of Collier and Lockwood's radiometer or in the way they scaled their chart records.

It is constructive to compare fluxes of total radiation calculated from the two empirical formulae discussed by Collier and Lockwood but there is an important restriction. Our own method for calculating S_t relies on an empirical relationship between the ratio of diffuse to total radiation and a turbidity coefficient τ_a. The relationship is valid only for solar elevations greater than 30° (air masses less than 2) and consequently on the three days analysed by Collier and Lockwood, comparison is appropriate only for eight hours on 20 August and for four hours on 14 October. In addition there appear to be arithmetic errors in Collier and Lockwood's application of our turbidity method.

In Table 1 we compare Lumb's formula calculated for 20 August with radiation calculated by our method for turbidities of $\tau_a = 0{\cdot}1$ and $\tau_a = 0{\cdot}25$. Mean values for precipitable water (2·3cm) and ozone (0·31cm) for August were used in the calculations (Bannon and Steele 1960; Robinson 1966), the solar constant was taken as 1353W m^{-2} and the appropriate value of the solar radius vector was used. The table also shows the insolation over the eight hours when the comparison is valid.

Lumb's formula agrees very closely with radiation calculated for $\tau_a = 0{\cdot}1$, a result consistent with our previous conclusions concerning average turbidity at remote or coastal sites in polar air masses. It so happens that on 20 August 1971, we measured τ_a during an ascent of Ben Nevis and found that τ_a was about 0·12 near sea level. The measurements at Eskdalemuir indicate that τ_a was slightly less than 0·1 at that site.

TABLE 1. COMPARISON OF MEASURED AND CALCULATED VALUES OF SOLAR RADIATION (Wm^{-2}) AND INSOLATION ($mJ\ m^{-2}$) ON 20 AUGUST 1971

GMT	sin θ	1	2	3	4	5	6	7
8–0900	0·529	352	520	68	511	491	421	86
9–1000	0·632	423	641	66	628	629	565	90
10–1100	0·704	473	711	67	714	723	666	92
11–1200	0·740	511	779	66	757	771	717	93
12–1300	0·737	515	782	66	754	764	710	93
13–1400	0·696	488	726	67	704	710	651	92
14–1500	0·619	428	581	74	613	608	543	90
15–1600	0·512	347	488	71	492	469	400	85
	ΣS_t ($mJ\ m^{-2}$)	12·7	18·8	68	18·6	18·6	16·7	90

1. Collier and Lockwood's measurements
2. Measurements at Eskdalemuir
3. (Column 1/Column 2) × 100
4. Lumb's equation
5. Our method, τ_a = 0·10
6. Our method, τ_a = 0·25
7. (Column 6/Column 5) × 100

In central England we found that the average of τ_a was about 0·25 and the corresponding radiation on 20 August is shown in Table 1. The final column in the Table is the ratio [Radiation (τ_a = 0·25)/Radiation (τ_a = 0·1)] showing that (i) the hourly mean radiation in central England ranges from 93 to 85% of radiation in the eastern Atlantic, and (ii) over eight hours, the insolation inland is 90% of the insolation over the ocean. We conclude that the corresponding figure of 60% quoted by Collier and Lockwood is based on a spurious agreement between faulty instrumental records and erroneous estimates derived from Lumb's work and our own.

We thank Mr. R. H. Collingbourne, Meteorological Office, for providing the Eskdalemuir record.

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REPLY

By L. R. COLLIER and J. G. LOCKWOOD

The available data and literature on the radiation climatology of Britain are extremely restricted compared with those on almost any other aspect of our climate. Since radiation climatology has been neglected in this country there is a need for some discussion of this particular topic.

When we checked our instruments we did not check the impedance of the millvoltmeter, but we have now measured this and found that we were assuming an incorrect value. Because of this regrettable experimental error, all the observations reported in our recent note (Collier and

Lockwood 1974) should be multiplied by 1·32. Allowing for this and including some more recent data, the empirical relationships between hourly solar radiation, Q, and solar altitude, θ, in our Fig. 1 now become:

A. $Q = 14{\cdot}22\theta \mathrm{W\,m^{-2}}$
B. $Q = 1380(-0{\cdot}010 + 0{\cdot}611 \sin\theta + 0{\cdot}146 \sin^2\theta)\mathrm{W\,m^{-2}}$
C. $Q = 1380(-0{\cdot}021 + 0{\cdot}718 \sin\theta)\mathrm{W\,m^{-2}}$
D. $Q = 1380 \sin\theta\,(0{\cdot}477 + 0{\cdot}363 \sin\theta)\mathrm{W\,m^{-2}}$

The best fits to the data are given by equations C and D. The large differences between our observations and those of Weather Ship *Juliett* have now disappeared.

Smith and Carson (1974) have recently published a diagram showing average hourly global radiation over monthly periods at Cambridge. Both our equation D and that from Lumb (1964) for Ship *Juliett* fit the spring and autumn values reasonably well, but overestimate the summer values at Cambridge. Because of midday cloud we have few observations for very large values of θ, and the same could apply at Cambridge, causing the average published values to be low. Alternatively, the atmospheric attentuation could increase during the summer at Cambridge. If the latter is true, our equation D overestimates global radiation for large values of θ, and this is better estimated using our equation C.

We used a modified version of Unsworth and Monteith's (1972) computer program for determining solar radiation. While the theory of their method is correct, in practice it involves a series of empirical approximations, several of which are not accurately known. It also requires a knowledge of the actual precipitable water and dust content of the atmosphere. Therefore the solar radiation values predicted are not of great accuracy, and it is safer to use for individual stations simple empirical equations of the type suggested by ourselves or Lumb. Average atmospheric attenuation varies because of variations in the average water vapour and dust content of the atmosphere and this is shown by the differing constants for equation D obtained by Lumb for ships *Alfa* and *Juliett* and ourselves for Harrogate. Average attenuation would appear to be less for large values of θ at ship *Alfa* than at ship *Juliett*.

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13 December 1974

551.509.313 : 551.515.1 : 551.551.5

COMMENT ON PAPER 'GRADIENT RICHARDSON NUMBER PROFILES AND CHANGES WITHIN AN INTENSE MID-TROPOSPHERIC BAROCLINIC ZONE' BY L. F. BOSART AND O. GARCIA

By W. T. ROACH

In their recent paper (*Q. J.*, October 1974) Bosart and Garcia have bravely attempted to apply my suggestion (Roach 1970) that rate of change of Richardson number (following the motion) might be a better indication of the presence of CAT than the conventional (and static) measurement of Richardson number.