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SOLAR RADIATION RECORDING AT MOOR HOUSE

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INTRODUCTION

One aim of the Moor House IBP programme was to provide an assessment of primary and secondary productivity in a moorland ecosystem and an understanding of the factors influencing this productivity. Clearly one of the climatic factors involved is solar radiation, particularly in relation to plant photosynthesis; therefore, when the Moor House IBP programme was being planned, it was decided to record total incoming solar radiation continuously.

Initially, a Kipp solarimeter linked to a Kent recorder was installed, but proved unsatisfactory mainly because of problems with the electricity supply from the generators and mechanical problems with the recorder. Dr. J. Grace, then a research student at Sheffield University, connected the Kipp solarimeter to a Kent clockwork recorder, and a useful run of data was obtained from May 1968 to April 1969. Extraction of data from the charts was difficult and, in April 1969, a Lintronic solarimeter and integrator-recorder were installed. Some runs of data were obtained, but, on the whole, the early performance of the equipment was very poor, due mainly to the following reasons:-

1. Unreliability of the integrator-recorder;
2. Condensation inside the Lintronic solarimeter dome;
3. The effect of changes in the ambient air temperature on the output of the Lintronic solarimeter;
4. The appreciable non-linearity of the Lintronic solarimeter: i.e. for any given temperature, the sensitivity of the solarimeter is not independent of the radiation intensity.

After consultation with the Meteorological Office (formerly Kew Observatory, Richmond, Surrey, and now Beaufort Park, Easthampstead, Wokingham, Berks.), the Lintronic solarimeters were abandoned and a Kipp solarimeter was connected to the Lintronic integrator-recorder. The use of a Kipp solarimeter overcomes most of the difficulties listed above. Compared with a Lintronic solarimeter, the sensitivity of the Kipp is more stable, it is less temperature sensitive, and is relatively free from condensation problems. The Kipp solarimeter was installed in September 1971, and, since that date, a continuous run of good data has been obtained up to the present day. It is proposed to continue data collection for the time being, particularly as the Meteorological Office are interested in receiving data from a high level station in the Pennines.

This paper describes the equipment and its maintenance; it also documents the results obtained to date. The feasibility of predicting solar radiation input from standard meteorological recording of sunshine is also examined.

METHOD

The equipment consists of the following:-

1. Solarimeter

This consists of a standard Moll-Gorczynski solarimeter manufactured by Kipp and Zonen, Delft, Holland. It is mounted on a concrete pillar 1.2 metres high situated on a knoll about 72 metres from the main laboratory. Care must be taken to prevent condensation inside the solarimeter. At Moor House, this is accomplished by inserting a small specimen tube containing dry silica gel crystals up the metal tube on the underside of the solarimeter body, and holding the tube in place with a tightly-fitting rubber bung; this method has proved quite satisfactory. The appearance of condensation would probably indicate an appreciable leak, due to the deterioration of either the cement used to seal the glass domes, or the rubber O-ring seal.

The solarimeter is connected to the integrator-recorder by a length of standard twin microphone cable. This cable has an internal metal braided screen surrounding the 2 cores; this screen is earthed to the casing of the integrator-recorder, and prevents electrical 'pick-up' on the cable causing extraneous counts on the integrator.

2. Integrator

This is a Lintronic Mk.IV integrating counter, which has an input signal range of 0-30 mV, and a count rate of 100 counts per mV hour. Read-out is on a six-place digital indicator. The unit is powered by 9 Mallory Duracell type MN 1300 size D batteries, which must be changed as soon as the overall battery voltage falls below 11 volts. In practice, the batteries are changed approximately 5-6 times per year.

3. Recorder

This is a Lintronic recorder comprising a battery operated clock and a Sodeco printer. The printer is powered by two 12-volt car accumulators, normally producing 18 volts, and never less than 12 volts. The recorder is switched to provide a printed record of the integrated count once every hour.

The integrator and recorder are located inside the main laboratory on a vibration free mounting, and are shielded from the direct rays of the sun. It will be noted that the entire installation is independent of mains electricity. Notes on the calibration of the solarimeter and integrator are contained in Appendix 1.

Data processing

The following are the units commonly used in solar radiation measurements, together with their conversion factors:-

1 Langley = 1 gm. calorie/cm^2;

1 gm. calorie/cm^2 x 1.16 = 1 milliwatt hour/cm^2;

1 milliwatt hour/cm^2 x 0.86 = 1 gm. calorie/cm^2;

1 watt hour x 3600 = 1 joule;

1 gm. calorie/min. x 69.7 = 1 milliwatt;

1 milliwatt x 0.014 = 1 gm. calorie/min.

The values of solar radiation are derived as follows:-

$$\frac{I_j - I_{j-1}}{T \times 100 \times S} \text{ mW hours/cm}^2\text{/hour}$$

where $\dfrac{I_j - I_{j-1}}{T \times 100}$ average input per hour in mV

and I_j = integrator counter reading;

I_{j-1} = previous integrator counter reading;

T = time in hours since previous reading;

S = sensitivity of solarimeter in mV/mW.cm^{-2}.

At the end of each calendar month, the hourly print-out from the Lintronic recorder is removed, annotated to indicate the output for each day in that month, and then posted to Merlewood. The data are punched in 4-weekly batches, and run with a FORTRAN computer program which produces, as a printed output, hourly, daily, weekly and 4-weekly totals, all in both milliwatt hours/cm^2 and gm. calories/cm^2. Two copies of each output are produced; one is filed at Merlewood, and the other is sent to the Meteorological Office (Beaufort Park). Finally, calendar monthly totals and annual totals are calculated by hand.

RESULTS

As stated in the introduction, the first reliable run of data was obtained by Dr. J. Grace, using a Kipp solarimeter linked to a clockwork Kent recorder. His results are summarised in Table 1.

The present run of data, derived from a Kipp solarimeter linked to a Lintronic integrator-recorder, commenced in September 1971, and will be continuing. Monthly and annual totals, up to the end of 1974, are listed in Table 2.

A brief comparison was made between Moor House and two other radiation recording stations. One of these was Eskdalemuir, Dumfriesshire; this is the nearest official Meteorological Office radiation recording site to Moor House. The other was Bracknell Berkshire, another official radiation recording station, selected to make a comparison with a site in southern England. A comparison of monthly totals is illustrated in Fig. 1, while a comparison of annual totals is shown in Table 3. It is clear that, in general, the southerly station receives more solar radiation, both in winter and summer. Also the overall results for the two northerly stations agree fairly closely.

PREDICTION

Measurements of solar radiation are available for only a few sites in Great Britain. However, sunshine recording, using Campbell-Stokes recorders, is widespread. A relationship between these measurements was expected and therefore the possibility of predicting solar radiation from sunshine records was examined. Prediction is also valuable when radiation data at a particular site are incomplete, because of instrument failure or because recording has to be discontinued for some other reason. There are now three years of reliable radiation data for Moor House. Using this information, some preliminary work has been carried out on the prediction of radiation in one year from relationships defined in another year, and then comparing predicted and observed results.

Most relationships between solar radiation and duration of bright sunshine are of the form:-

$$Q = Q_A \, (a + b. \frac{n}{N})$$

where Q = radiation actually received on a horizontal surface at ground level in gm.cals/cm^2/day;

Q_A = radiation received on a horizontal surface at the top of the atmosphere in gm.cals/cm^2/day;

n = daily hours of bright sunshine measured on a Campbell-Stokes sunshine recorder;

N = maximum possible duration of sunshine i.e. day length in hours;

a = regression constant;

b = regression coefficient.

Values of Q_A and N

Q_A is the theoretically possible mean solar radiation per unit horizontal surface per day at the top of the atmosphere. It is obtained using a method based on the equation given by Sellers (1965), using slightly different notation:-

$$Q_A = \frac{1440}{\pi} \cdot I_o/a^2 \, (H. \sin \theta \sin \cdot \delta + \cos \theta \overset{\cos}{\cancel{\sin}} \delta \sin H)$$

where 1440 = no. of minutes per 24 hours;

I_o = solar constant = 2.00 calories/cm^2/min;

e = radius vector, i.e. ratio of the earth-to-sun distance, at a particular time, to its mean;

H = wt, where w = angular velocity of earth's rotation = 15 degrees per hour and t = ½ daylength (hours);

Θ = terrestrial latitude;

δ = solar declination.

All angles are calculated in radians; I_o/e^2 can be interpolated from values given by Frank and Lee (1966). Using a program SLRD in conjunction with the Merlewood TSS-8 computer, it is possible to obtain a tape or printout listing the values of Q_A in gm.calories/cm^2/day for each day in the year for any specified latitude.

N is the maximum possible duration of sunshine i.e. the daylength. The calculations have been made for the passage of the sun's centre past the horizon. The method is based on the equation given by Frank and Lee (1966):-

$$\cos wt = -\tan \Theta \ \tan \delta$$

where w = angular velocity of earth's rotation = 15 degrees per hour

t = time in hours from noon;

Θ = terrestrial latitude;

δ = solar declination

The mean daily solar declination per month can be interpolated from List (1951).

Using a program SOLD, it is possible to obtain values for the half-day length (in hours and minutes) for each day in the year for any specified latitude.

Calculations

1. Regression parameters

The values of Q & Q_A (gm. calories/cm^2/day) and n & N (hours) for each day throughout 1972, 1973 and 1974, were listed, and the monthly totals of each were calculated. Using the equation

$$\frac{Q}{Q_A} = a + b. \frac{n}{N} \qquad (1)$$

the regression between $\frac{Q}{Q_A}$ and $\frac{n}{N}$ was computed for

each month separately, and thereby the monthly values of the regression constant (a), the regression coefficient (b) and the correlation coefficient (r) were obtained (Table 4).

2. Predictions from monthly regression parameters

Equation (1) was then transposed into the form

$$Q = Q_A \left(a + b.\, \frac{n}{N}\right) \qquad (2)$$

The monthly values of Q for one year were predicted by substituting the corresponding monthly totals of Q_A, n & N for the same year, and the monthly values of the regression parameters a & b (from Table 4), for another year. Thus, to predict monthly values of Q for 1972 from the 1973 regressions, monthly totals of Q_A, n and N for 1972 and the monthly values of a & b for 1973 were substituted in equation (2). The predicted values obtained are tabulated in Tables 5, 6 and 7, which also list the corresponding observed values, and the deviations from them.

The regression equations between observed (x) and predicted (y) values are listed in Table 13, and, as an example, observed values for 1972 are shown plotted against predicted values, derived from the 1973 regressions, in Fig. 2.

3. Prediction from annual mean regression parameters

It will be noted from Table 4 that there is an absence of any apparent seasonal pattern in the regression constants and coefficients. The previous calculations were therefore repeated using the annual means of the regression parameters a & b (from Table 4) in place of the monthly values. The predicted values obtained are tabulated in Tables 8, 9 and 10 which also list the corresponding observed values and the deviations from them. The regression equations between observed (x) and predicted (y) values are listed in Table 13, and, as an example, observed values for 1972 are shown plotted against predicted values, derived from the 1973 regression, in Fig. 3.

4. Prediction of daily values

Finally, the use of this method to predict daily values was tested. Using the months of February and August in both 1972 and 1973, daily values of Q were predicted for each month using the corresponding monthly regression parameters determined for the same month during the other year. The predicted values were then compared with the corresponding observed values; as examples, daily values during February and August 1973 predicted from the corresponding regressions for February and August 1972 are listed in Tables 11 and 12, together with the corresponding observed values and the deviations from them. The regression equations are listed in Table 13, and, as an example, daily observed values for February 1973 are shown plotted against predicted values, derived from the February 1972 regression, in Fig. 4.

Results

The correlation coefficients in Table 13 are all very highly significant ($P<0.001$). However it will be seen from Tables 4 and 13 that the poorest fits (r values) occur during the winter months. This is also shown in Fig. 5 where deviation (expressed as a percentage of the observed value) between observed and predicted monthly values in 1972, 1973 and 1974 (from Tables 5, 6 and 7) is plotted against the observed radiation level, and the deviation clearly increases at low radiation levels. This demonstrates a poorer relationship between radiation and sunshine hours at low levels of radiation; appreciable radiation is received on dull days when there is no burn on the sunshine chart, and this effect is more marked during the winter months.

From Table 13 it can be seen that when predicting monthly values using monthly regression parameters, 42-75% of the predictions are within ± 5% of the observed values; when using annual mean regression parameters, 25-67% are within ± 5% of the observed values. The prediction of daily values from monthly regression parameters is much less accurate; for the four months examined only 11-32% of the predictions are within ± 5% of the observed values.

Conclusion

As only three years data are compared, conclusions must be tentative. However, by using monthly regression parameters it appears that reasonably accurate and useful predictions of monthly totals of incoming solar radiation can be made from corresponding monthly totals of sunshine duration. The accuracy diminishes when attempts are made to predict radiation for shorter periods, and daily predictions based on corresponding daily sunshine duration records would be unreliable. If several years records of both solar radiation and sunshine duration are available for comparison, the method could probably be slightly refined by determining mean monthly regression parameters which could then be used for predicting the incoming solar radiation in future years. It should be emphasised that the regression parameters used in this paper have been determined specifically for the latitude of Moor House, and that, for another location at a different latitude, the parameters would have to be re-calculated.

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APPENDIX 1

Calibration

1. The Kipp solarimeter

Calibration is carried out by the Meteorological Office. Kipp solarimeters in continuous use should be calibrated at intervals of not more than two years, unless condensation appears, in which case the instrument should be repaired and re-calibrated as soon as possible. When a solarimeter is returned for re-calibration, a spare instrument is installed so that recording remains uninterrupted.

2. The integrator

The integrator count rate should be 100 counts per mV hour. It is necessary to check the consistency of this calibration factor from time to time; this is done approximately every six months. On each occasion that the recorder has been checked it was found to be approximately ± 3% off calibration. The pattern of this drift and the reasons for it have not been determined.

To re-calibrate the integrator it is necessary to carry out the following procedure:-

i) Cover the Kipp solarimeter with a tin to exclude all light.

ii) Place a 10 mV test source in series with the head, so that the complete circuit, including the head, is tested. It may be necessary to check beforehand that the test source is emitting exactly 10 mV.

iii) Switch on the integrator and note the number of counts over a period of exactly one hour.

iv) If the number of counts is greater or less than 1000 ± 5, remove the back of the integrator to expose the printed circuit.

v) Locate a grey rectangular potientiometer at the edge of the printed circuit, about ¾" long by 3/16" wide, with an adjustable screw facing upwards.

vi) Note the position of the screw. If the count recorded at iii was greater than 1000 ± 5, turn the screw counter-clockwise ½ turn.

vii) Re-check the number of counts per hour with the 10 mV source. If still above 1000 ± 5, turn the screw back another ½ turn. The first ½ turn may be ineffective due to backlash in the screw adjustment.

viii) Repeat the procedure until the number of counts per hour is exactly 1000 ± 5.

ix) If the number of counts per hour at iii was less than 1000 ± 5, the procedure is similar except that the screw is turned clockwise each time, until the number of counts per hour is exactly 1000 ± 5.

The accuracy of the integrator is quoted as follows: "± ½% of reading or ± 2 least significant digits, whichever is the greater". For example, at 100 counts the accuracy is within ± 2 counts (± 2 least significant digits), and at 1000 counts the accuracy is within ± 5 counts (± ½% of reading).

TABLE 1. Solar radiation recorded at Moor House by Dr. J. Grace using a Kipp solarimeter and Kent clockwork recorder (gm.cal/cm2) (Grace, 1970).

Period		Radiation received
1968		
	May	9,500
	June	12,200
	July	7,800
	August	8,200
	September	5,000
	October	2,500
	November	1,400
	December	1,100
1969		
	January	900
	February	3,000
	March	5,000
	April	7,000
Annual total		63,600

TABLE 2. Solar radiation recorded at Moor House, using a Kipp solarimeter and Lintronic integrator/recorder (gm.cals/cm^2).

Month	1971	1972	1973	1974
January		961	1,286	927
February		2,152	3,397	2,252
March		5,749	6,400	5,532
April		7,111	7,809	9,869
May		8,322	10,083	11,532
June		10,115	11,201	12,497
July		10,938	10,422	9,111
August		9,577	9,744	7,999
September		6,403	5,910	5,202
October	3,449	3,833	3,288	2,634
November	1,526	1,590	1,998	1,276
December	668	1,027	869	651
Annual total	-	67,778	72,407	69,482

TABLE 3. Annual totals of solar radiation at Moor House and Eskdalemuir, compared with those at Bracknell (gm. cals/cm^2).

	1972	1973	1974	Mean	% of Bracknell
Moor House	67,778	72,407	69,482	69,889	81.6
Eskdalemuir	73,462	71,924	71,325	72,237	84.4
Bracknell	82,619	89,560	84,675	85,618	100

TABLE 4. Regression parameters for solar radiation against sunshine hours at Moor House for 1972, 1973 and 1974.

Month	1972			1973			1974		
	a	b	r	a	b	r	a	b	r
January	0.136	0.811	0.806	0.169	0.618	0.872	0.151	0.679	0.821
February	0.187	0.631	0.796	0.234	0.629	0.825	0.183	0.677	0.860
March	0.208	0.592	0.928	0.217	0.567	0.923	0.183	0.706	0.908
April	0.197	0.582	0.929	0.176	0.659	0.926	0.186	0.587	0.951
May	0.159	0.634	0.945	0.164	0.615	0.946	0.205	0.522	0.950
June	0.170	0.589	0.963	0.184	0.576	0.913	0.214	0.564	0.967
July	0.194	0.530	0.959	0.169	0.607	0.938	0.179	0.541	0.857
August	0.172	0.594	0.949	0.179	0.595	0.944	0.156	0.564	0.904
September	0.209	0.501	0.946	0.190	0.555	0.953	0.162	0.565	0.924
October	0.156	0.581	0.957	0.161	0.647	0.961	0.153	0.657	0.863
November	0.188	0.734	0.843	0.167	0.595	0.923	0.143	0.723	0.849
December	0.174	0.596	0.844	0.151	0.664	0.915	0.128	0.639	0.823
Annual mean	0.179	0.615	0.905	0.180	0.611	0.920	0.170	0.619	0.890

Regression equation is of the form $y = a + bx$, where $x = \frac{n}{N}$, $y = \frac{Q}{Q_A}$

a = regression constant, b = regression coefficient and r = correlation coefficient.

TABLE 5. Monthly values of solar radiation (gm.cals/cm^2) at Moor House for 1972, predicted from individual monthly regression parameters for 1973 and 1974 (Table 4), together with the corresponding observed values.

Month	Observed	1973 parameters			1974 parameters		
		Predicted	Deviation (Obs-Pred)	Deviation as % of observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed
January	961	1,012	-51	-5.3	939	+22	+2.3
February	2,152	2,485	-333	-15.5	2,123	+29	+1.3
March	5,749	5,693	+56	+1.0	5,769	-20	-0.3
April	7,111	7,002	+109	+1.5	6,872	+239	+3.4
May	8,322	8,379	-57	-0.7	8,973	-651	-7.8
June	10,115	10,438	-323	-3.2	11,223	-1,108	-11.0
July	10,938	10,920	+18	+0.2	10,590	+348	+3.2
August	9,577	9,820	-243	-2.5	8,964	+613	+6.4
September	6,403	6,332	+71	+1.1	5,887	+516	+8.1
October	3,834	4,017	-183	-4.8	3,960	-126	-3.2
November	1,590	1,387	+203	+12.8	1,334	+256	+16.1
December	1,027	996	+31	+3.0	893	+134	+13.0
Annual mean	5,648	5,707	140	4.3	5,627	339	6.3

TABLE 6. Monthly values of solar radiation (gm.cals/cm^2) at Moor House for 1973, predicted from individual monthly regression parameters for 1972 and 1974 (Table 4), together with the corresponding observed values.

Month	Observed	1972 parameters Predicted	1972 parameters Deviation (Obs-Pred)	1972 parameters Deviation as % of observed	1974 parameters Predicted	1974 parameters Deviation (Obs-Pred)	1974 parameters Deviation as % of observed
January	1,286	1,298	-12	-0.9	1,269	+17	+1.3
February	3,397	3,013	+384	+11.3	3,000	+397	+11.7
March	6,400	6,363	+37	+0.6	6,591	-191	-3.0
April	7,810	7,825	-15	-0.2	7,630	+180	+2.3
May	10,083	10,106	-23	-0.2	10,417	-334	-3.3
June	11,201	10,921	+280	+2.5	12,007	+806	+7.2
July	10,422	10,500	-78	-0.7	10,170	+252	+2.4
August	9,744	9,543	+201	+2.1	8,889	+855	+8.8
September	5,910	5,958	-48	-0.8	5,407	+503	+8.5
October	3,288	3,075	+213	+6.5	3,211	+77	+2.3
November	1,998	2,425	-427	-21.4	2,140	-142	-7.1
December	869	923	-54	-6.2	766	+103	+11.9
Annual mean	6,034	5,996	148	4.5	5,958	321	5.8

TABLE 7. Monthly values of solar radiation (gm.cals/cm^2) at Moor House for 1974, predicted from individual monthly regression parameters for 1972 and 1973 (Table 4), together with the corresponding observed values.

		1972 parameters			1973 parameters		
Month	Observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed
January	927	891	+36	+3.9	993	-66	-7.1
February	2,252	2,212	+40	+0.9	2,582	-330	-14.7
March	5,532	5,465	+67	+1.2	5,510	+22	+0.4
April	9,869	10,145	-276	-2.8	10,448	-579	-5.9
May	11,532	11,464	+68	+0.6	11,408	+124	+1.1
June	12,497	11,434	+1,063	+8.5	11,705	+792	+6.3
July	9,111	9,480	-369	-4.1	9,270	-159	-1.7
August	7,999	8,586	-587	-7.3	8,763	-764	-9.6
September	5,202	5,834	-632	-12.1	5,727	-525	-10.1
October	2,634	2,564	+70	+2.6	2,712	-78	-2.9
November	1,276	1,547	-271	-21.2	1,340	-64	-5.0
December	651	820	-169	-26.0	747	-96	-14.7
Annual mean	5,790	5,870	304	7.6	5,934	300	6.6

TABLE 8. Monthly values of solar radiation (gm.cals/cm^2) at Moor House for 1972, predicted from annual mean regression parameters for 1973 and 1974 (Table 4), together with the corresponding observed values.

Month	Observed	1973 parameters			1974 parameters		
		Predicted	Deviation (Obs-Pred)	Deviation as % of observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed
January	961	1,060	-99	-10.3	1,017	-56	-5.8
February	2,152	2,035	+117	+5.4	1,962	+190	+8.8
March	5,749	5,313	+436	+7.6	5,191	+558	+9.7
April	7,111	6,850	+261	+3.7	6,677	+434	+6.1
May	8,322	8,804	-482	-5.8	8,549	-227	-2.7
June	10,115	10,619	-504	-5.0	10,378	-263	-2.6
July	10,938	11,280	-342	-3.1	11,070	-132	-1.2
August	9,577	9,971	-394	-4.1	9,795	-218	-2.3
September	6,403	6,456	-53	-0.8	6,314	+89	+1.4
October	3,834	4,119	-285	-7.4	4,028	-194	-5.1
November	1,590	1,476	+114	+7.2	1,423	+167	+10.5
December	1,027	1,073	-46	-4.5	1,042	-15	-1.5
Annual mean	5,648	5,755	261	5.4	5,621	212	4.8

TABLE 9. Monthly values of solar radiation (gm.cals/cm^2) at Moor House for 1973, predicted from annual mean regression parameters for 1972 and 1974 (Table 4), together with the corresponding observed values.

Month	Observed	1972 parameters			1974 parameters		
		Predicted	Deviation (Obs-Pred)	Deviation as % of observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed
January	1,286	1,351	-65	-5.1	1,312	-26	-2.0
February	3,397	2,912	+485	+14.3	2,767	+630	+18.5
March	6,400	6,043	+357	+5.6	5,921	+479	+7.5
April	7,810	7,630	+180	+2.3	7,479	+331	+4.2
May	10,083	10,502	-419	-4.2	10,275	-192	-1.9
June	11,201	11,434	-233	-2.1	11,223	-22	-0.2
July	10,422	10,800	-378	-3.6	10,590	-168	-1.6
August	9,744	9,921	-177	-1.8	9,719	+25	+0.3
September	5,910	5,922	-12	-0.2	5,780	+130	+2.2
October	3,288	3,416	-128	-3.9	3,325	-37	-1.1
November	1,998	2,158	-160	-8.0	2,110	-112	-5.6
December	869	950	-81	-9.3	916	-47	-5.4
Annual mean	6,034	6,087	223	5.0	5,951	183	4.2

TABLE 10. Monthly values of solar radiation (gm.cals/cm^2) at Moor House for 1974, predicted from annual mean regression parameters for 1972 and 1973 (Table 4), together with the corresponding observed values.

Month	Observed	1972 parameters			1973 parameters		
		Predicted	Deviation (Obs-Pred)	Deviation as % of observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed
January	927	1,041	-114	-12.3	1,046	-119	-12.8
February	2,252	2,123	+129	+5.7	2,131	+121	+5.4
March	5,532	5,115	+417	+7.5	5,115	+417	+7.5
April	9,869	10,080	-211	-2.1	10,058	-189	-1.9
May	11,532	11,832	-300	-2.6	11,804	-272	-2.4
June	12,497	11,977	+520	+4.2	11,947	+550	+4.4
July	9,111	9,630	-519	-5.7	9,630	-519	-5.7
August	7,999	8,914	-915	-11.4	8,914	-915	-11.4
September	5,202	5,780	-578	-11.1	5,780	-578	-11.1
October	2,634	2,871	-237	-9.0	2,882	-248	-9.4
November	1,276	1,423	-147	-11.5	1,423	-147	-11.5
December	651	843	-192	-29.5	847	-196	-30.1
Annual mean	5,790	5,969	357	9.4	5,965	356	9.5

TABLE 11. Predicted daily values of solar radiation ($gm.cals/cm^2$) at Moor House for February 1973, using the regression parameters derived for February 1972 (Table 4), together with the corresponding observed values.

Date	Observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed
1	95	77	+18	+18.9
2	99	105	- 6	- 6.1
3	64	41	+23	+35.9
4	67	42	+25	+37.3
5	93	111	-18	-19.4
6	7	44	-37	-528.6
7	70	107	-37	-52.9
8	69	69	0	0.0
9	67	54	+13	+19.4
10	107	96	+11	+10.3
11	45	52	- 7	-15.6
12	49	53	- 4	- 8.2
13	135	98	+37	+27.4
14	154	101	+53	+34.4
15	169	130	+39	+23.1
16	183	163	+20	+10.9
17	182	144	+38	+20.9
18	85	58	+27	+31.8
19	108	63	+45	+41.7
20	139	168	-29	-20.9
21	102	102	0	0
22	71	92	-21	-29.6
23	119	72	+47	+39.5
24	196	182	+14	+ 7.1
25	217	174	+43	+19.8
26	210	174	+36	+17.1
27	245	170	+75	+30.6
28	251	241	+10	+ 4.0
Mean			26.2	40.0

TABLE 12. Predicted daily values of solar radiation ($gm.cals/cm^2$) at Moor House for August 1973, using the regression parameters derived for August 1972 (Table 4), together with the corresponding observed values.

Date	Observed	Predicted	Deviation (Obs-Pred)	Deviation as % of observed
1	534	644	-110	-20.6
2	152	155	- 3	- 2.0
3	189	167	+ 22	+11.6
4	286	279	+ 7	+ 2.4
5	561	449	+112	+20.0
6	207	239	- 32	-15.5
7	332	360	- 28	- 8.4
8	374	337	+ 37	+ 9.9
9	74	148	- 74	-100.0
10	288	227	+ 61	+21.2
11	273	242	+ 31	+11.4
12	493	481	+ 12	+ 2.4
13	528	522	+ 6	+ 1.1
14	561	557	+ 4	+ 0.7
15	551	597	- 46	- 8.3
16	435	417	+ 18	+ 4.1
17	505	440	+ 65	+12.9
18	502	379	+123	+24.5
19	92	137	- 45	-48.9
20	76	136	- 60	-78.9
21	277	186	+ 91	+32.9
22	76	133	- 57	-75.0
23	460	444	+ 16	+ 3.5
24	209	198	+ 11	+ 5.3
25	121	133	- 12	- 9.9
26	390	457	- 67	-17.2
27	262	224	+ 38	+14.5
28	357	294	+ 63	+17.6
29	137	137	0	0
30	312	318	- 6	- 1.9
31	130	125	+ 5	+ 3.8
Mean			40.7	18.9

TABLE 13. Regression equations between observed (x) and predicted (y) values of solar radiation at Moor House.

Month/ Year	Predicted values M = monthly D = daily	Regression from which prediction was made		Regression equation	r	Percentage of predictions which are within		
						± 5%	± 10%	± 20%
						of observed values		
1972	M	Monthly	1973	$y = 2.70 + 1.01\ x$	0.9989	75.0	83.3	100.0
	M	Monthly	1974	$y = -148.57 + 1.02\ x$	0.9921	50.0	75.0	100.0
1973	M	Monthly	1972	$y = 45.55 + 0.99\ x$	0.9985	66.7	83.3	91.7
	M	Monthly	1974	$y = -164.85 + 1.01\ x$	0.9941	50.0	83.3	100.0
1974	M	Monthly	1972	$y = 244.22 + 0.97\ x$	0.9949	58.3	75.0	83.3
	M	Monthly	1973	$y = 264.79 + 0.98\ x$	0.9958	41.7	75.0	100.0
1972	M	Annual	1973	$y = -128.92 + 1.04\ x$	0.9977	50.0	91.7	100.0
	M	Annual	1974	$y = -150.81 + 1.02\ x$	0.9977	50.0	91.7	100.0
1973	M	Annual	1972	$y = -110.87 + 1.03\ x$	0.9979	58.3	91.7	100.0
	M	Annual	1974	$y = -140.49 + 1.01\ x$	0.9977	66.7	91.7	100.0
1974	M	Annual	1972	$y = 175.75 + 1.00\ x$	0.9957	25.0	58.3	91.7
	M	Annual	1973	$y = 187.31 + 1.00\ x$	0.9956	25.0	58.3	91.7
Feb 1972	D	Monthly	Feb 1973	$y = 37.04 + 0.70\ x$	0.8107	27.6	27.6	34.5
Feb 1973	D	Monthly	Feb 1972	$y = 16.76 + 0.74\ x$	0.9007	10.7	21.4	50.0
Aug 1972	D	Monthly	Aug 1973	$y = 44.23 + 0.88\ x$	0.9457	12.9	25.8	35.5
Aug 1973	D	Monthly	Aug 1972	$y = 26.64 + 0.90\ x$	0.9454	32.3	48.4	71.0

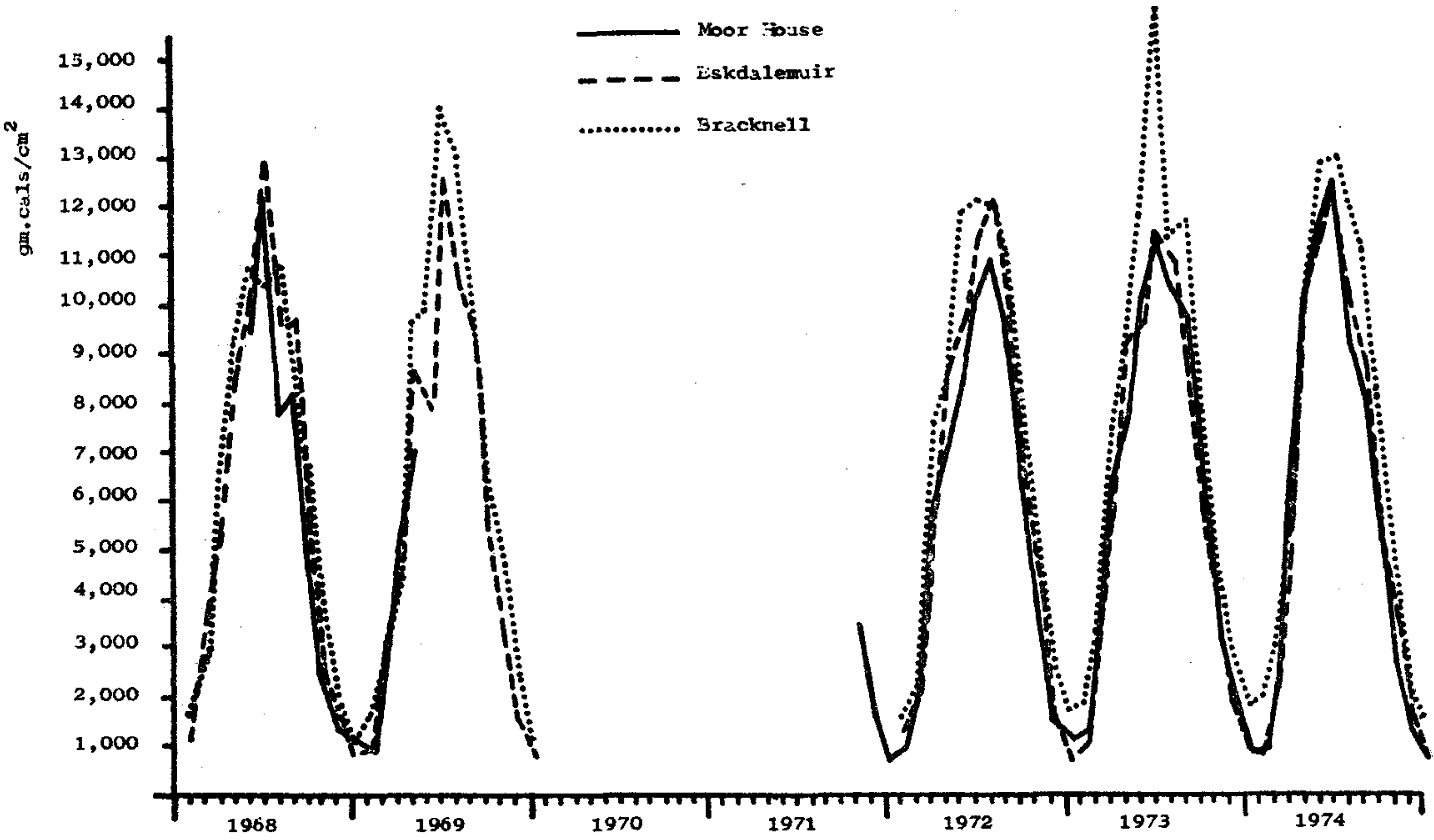

Fig. 1. Monthly totals of solar radiation at Moor House, Eskdalemuir and Bracknell (gm.cals/cm^2).

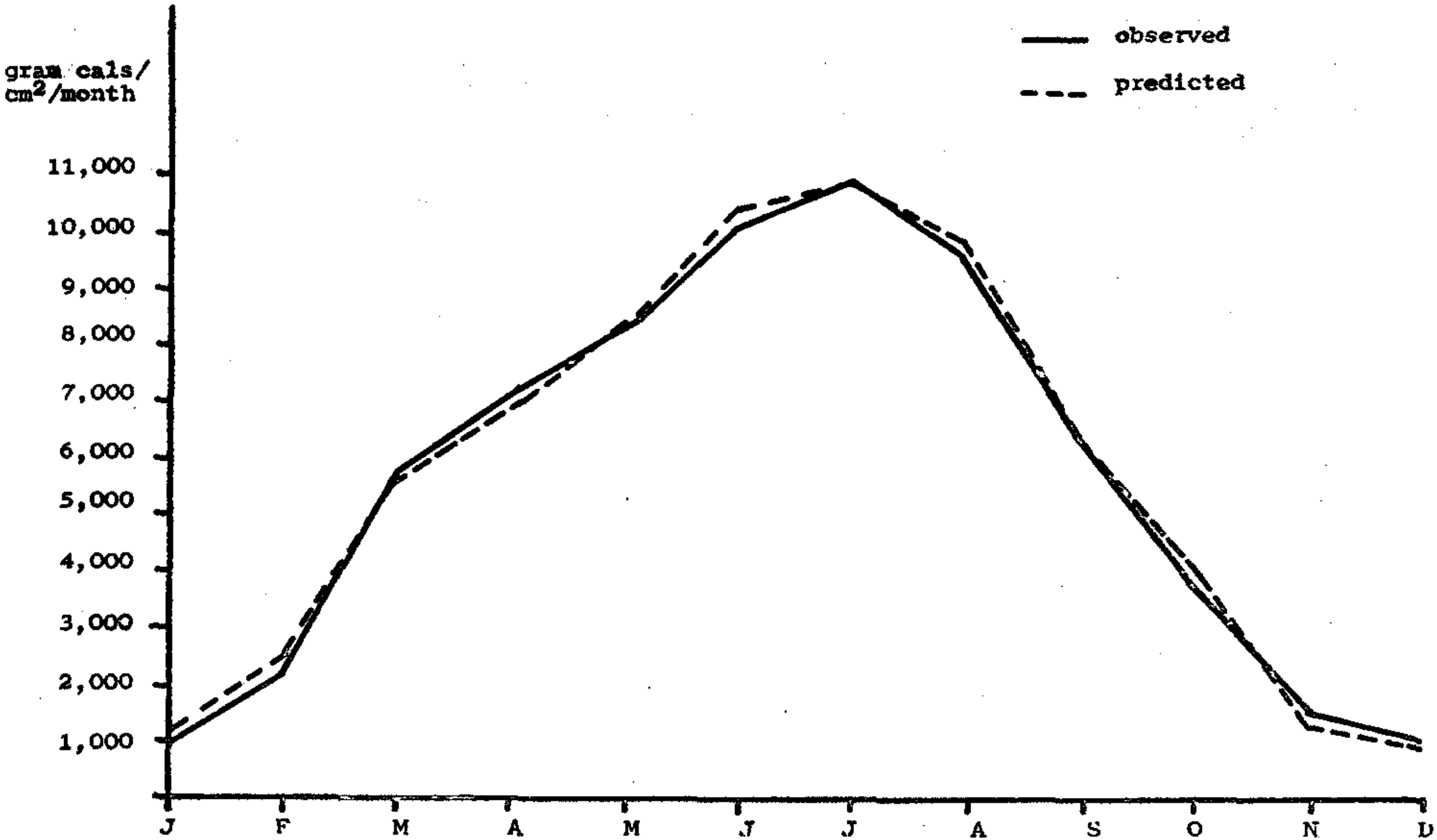

Fig. 2. Monthly values of observed solar radiation at Moor House for 1972 together with the predicted values derived from the 1973 monthly regressions.

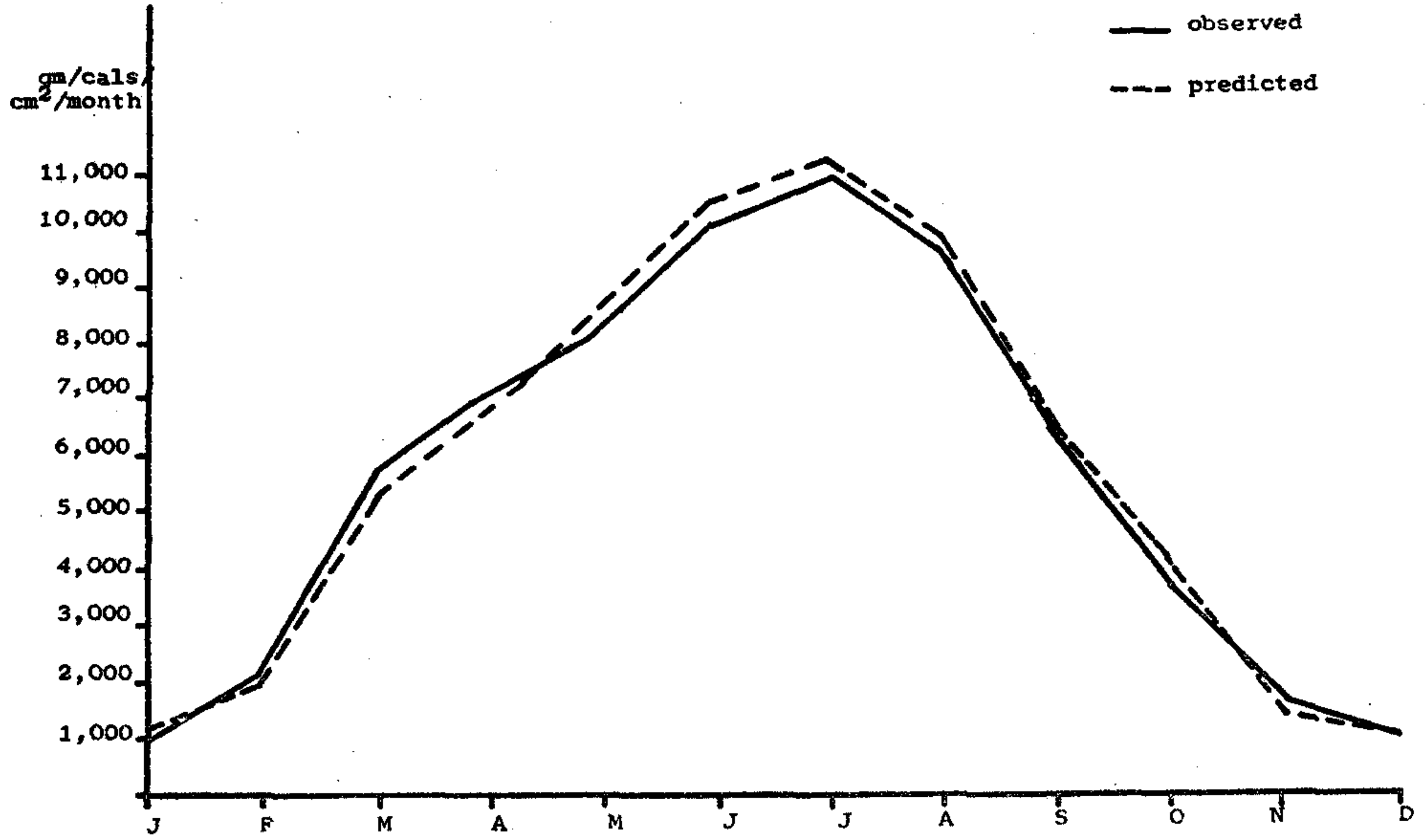

Fig. 3. Monthly values of observed solar radiation at Moor House for 1972 together with the predicted values derived from the 1973 annual regression.

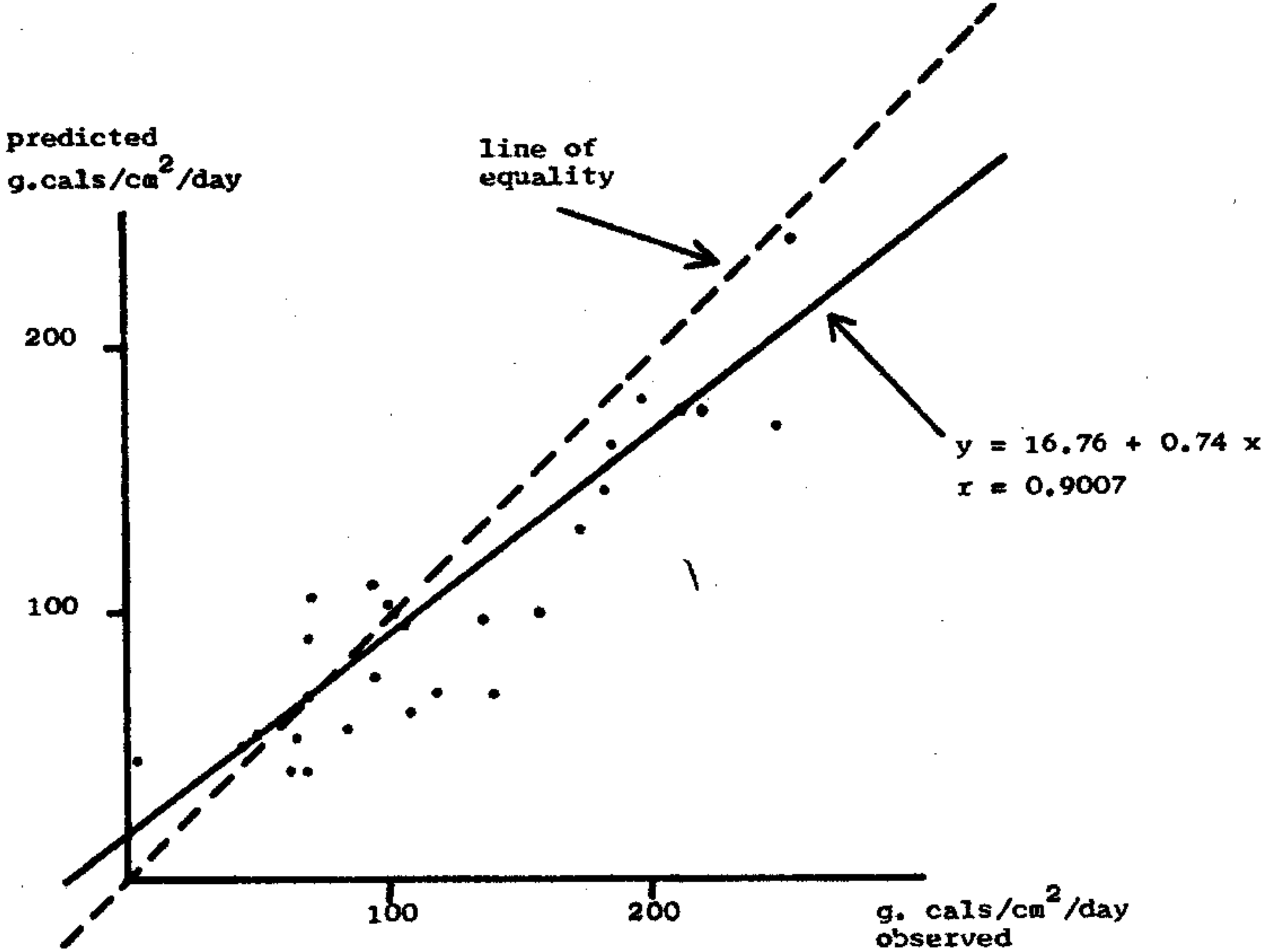

Fig. 4. Daily values of observed solar radiation at Moor House for February 1973 together with the predicted values derived from the February 1972 regression.

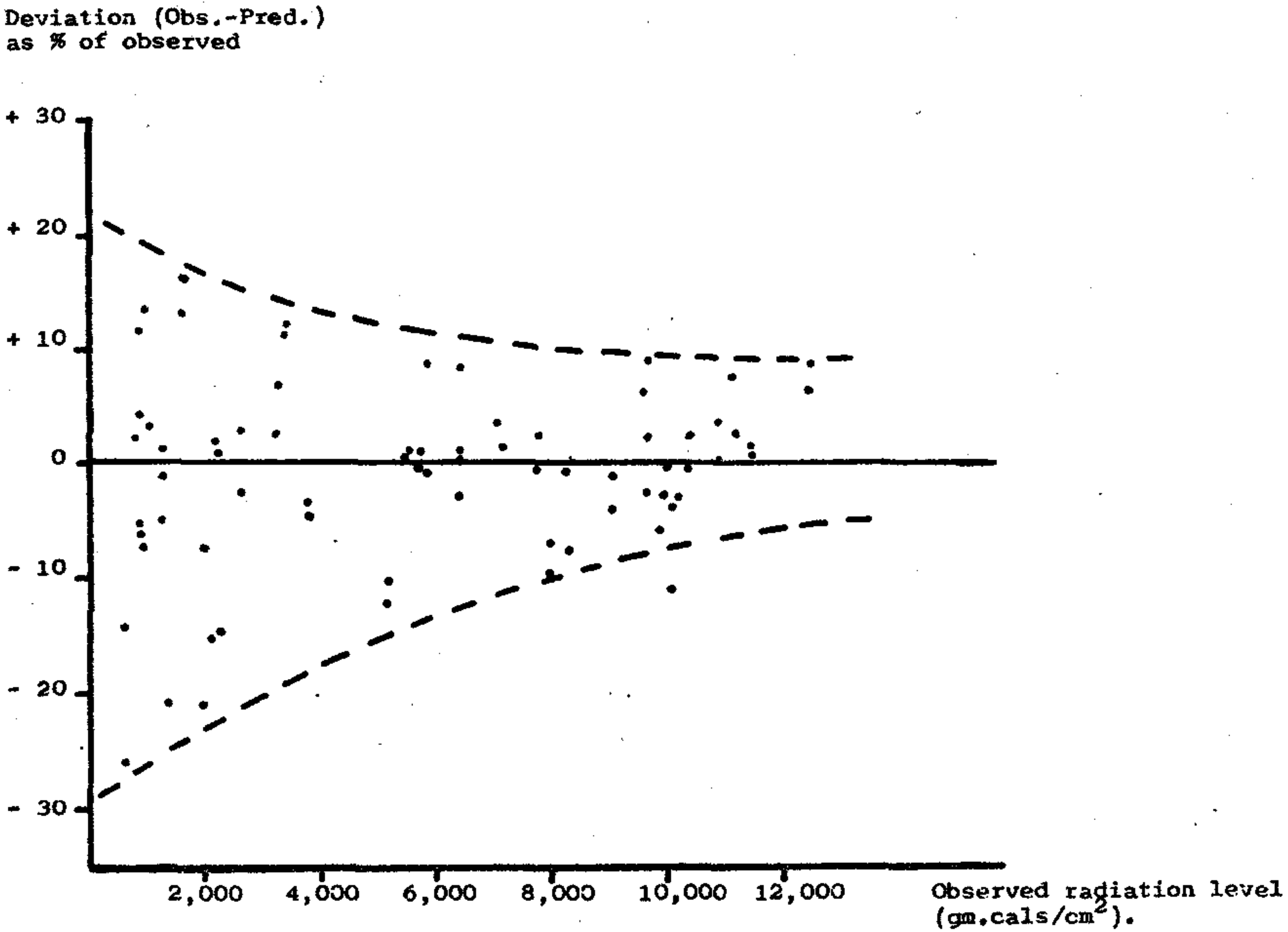

Fig. 5. Monthly values of observed solar radiation for 1972, 1973 and 1974 (from Tables 5, 6 and 7) plotted against deviation between observed and predicted values. Broken line delineates dotted area.