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THE SCOTTISH GEOGRAPHICAL MAGAZINE.

ON SUNSHINE.

By H. N. DICKSON, F.R.S.E.

(With a Map.)

To obtain a satisfactory working definition of the term sunshine is more difficult than is at first apparent. The "possible sunshine," or maximum time during which any direct rays from the sun can reach a point on the earth's surface is, of course, limited by the interval between sunrise and sunset—this much was included in the philosophy of Corin the shepherd—but when we come to decide whether, at any given instant, the sun is actually "shining" or not, we introduce subjective considerations of some complexity.

The sun emits, in different proportions, rays of various wave-lengths; and the radiations made up of these are capable of producing certain effects which appeal to our senses in different ways; some are known to us by the results of chemical action on particular substances, others by sensations produced on the retina of the eye, and yet others are recognised as heat effects. So far as we know, the relative proportions of rays leaving the sun remain unchanged until these rays reach the outer boundary of the atmosphere, but in transmission to the earth's surface absorption takes place, amounting, according to Langley's researches, to as much as 40 per cent. of the whole; and in the course of absorption the proportions of rays of different wave-lengths are changed, for the atmosphere exhibits selective powers, stopping some rays more readily than others. While there is, on the whole, a marked tendency towards special selection of certain rays in preference to others, the relative amounts absorbed are continually varying, and in this way the radiations reaching the earth's surface from the sun are made up, at different times, of different constituents; or, at least, the same constituents are present in different proportions. But the variation of the constituent rays produces corresponding changes in the different radiation

effects; a given intensity of chemical action does not necessarily correspond to a fixed brightness, or to a definite intensity of radiant heat. The photographer knows that the same brightness of sunlight does not always correspond to the same energy of chemical action, and strives to cultivate the actinic eye: and on bright days the sun seems sometimes to possess little "heating power."

The exact nature of the process of atmospheric absorption is far from being fully understood. Perfectly clear dry air is probably almost quite transparent to the sun's rays, and although conclusive proof is not forthcoming, it is usually assumed that *dry* aqueous vapour has little absorptive power. The stoppage of rays in transit through the atmosphere is chiefly effected by the minute dust-particles everywhere present, and the nature of the absorption depends in great measure on their size and number. When the dry air is comparatively dust-free, or the particles very small, few rays are stopped in their course, and the sun's disc appears accordingly very bright: there is at the same time relatively little scattered light, and the sky has a dark blue colour. If the suspended particles increase in number and size, the rays of shorter wave-length and less penetrative power are stopped first, the sky appears lighter in colour, tending towards a whitish "sickly" hue, while only red rays of longer wave-length are transmitted freely, and the sun accordingly appears red. The actual size and number of the dust-particles in the air vary greatly from time to time and from place to place, but, apart from these changes, the particles perform an important function as nuclei for condensation of the aqueous vapour in the atmosphere. When a certain humidity, probably always below saturation, is reached, each particle has a certain amount of water deposited on it, depending partly on the total number present, and partly on the substance of which each is composed: with a given allowance of vapour each particle receives more water the fewer there are present, and some substances, such as salt thrown into the air from sea-spray, have great power of attracting moisture. The water thus deposited increases the size of the particles and therefore their power of arresting the solar rays, until as an extreme case visible cloud is formed and the direct rays are practically stopped altogether.

Since we can estimate the duration or intensity of sunshine only by measuring its effects, we are therefore warned that a measurement of heat effect does not necessarily afford a corresponding estimate of light or actinic effect. It would be necessary, in order to determine fully the total energy of the solar rays at any point, to measure the intensity of heat, of light, and of chemical action, and in some way to combine the three together.

The experimental difficulties in the way of observing the intensities of any solar radiations are so great that as yet it has not been possible to devise a method capable of general application at observing stations. Up to the present time the only data obtainable are those of duration, and we may take photographic sunshine recorders as recording the duration of "actinic sunshine," burning sunshine recorders of direct sun-*heat*, and cloud observations as affording an estimate of direct sun-*light*. Here again, however, it is impossible to make satisfactory comparisons; because

each of the instruments—the photographic recorder, the burning recorder, and the eye—has a quite arbitrary inferior limit of sensitiveness, which is different in each case. Usually, although not invariably, the Jordan photographic recorder registers a considerably greater amount of sunshine than the Campbell-Stokes burning recorder; seventeen months' comparative observations at Torquay¹ gave an average monthly excess of 22 per cent., ranging from 5 to 44 per cent., but this is certainly largely due to the greater sensitiveness of the former instrument, a very slight obscuration of the sun's disc being sufficient to interrupt the record of the latter, so that all sunshine falling below a high standard of heat intensity is entirely left out of account.

As the eye is unfortunately not a self-recording instrument, cloud observations are defective as regards continuity, and may be dismissed with the remark that when sufficiently frequent they show that in general the records of direct sun-light follow the indications of those of direct sun-heat.

It remains, therefore, failing the possibility of strict comparison, to choose, on grounds of practical utility, between the photographic and burning records. So far as scientific meteorology is concerned, the choice undoubtedly lies with the latter. The physical conditions of the atmosphere are ultimately dependent on sun-heat, the grand problem of meteorology being, in fact, to explain the phenomena of atmospheric circulation as consequences of gain and loss of heat by radiation; and it therefore seems obvious that the more generally useful sunshine recorder is one which registers the length of time during which the sun's rays exceed a certain minimum of heat intensity. On the other hand, the light and actinic effects are extremely important in all applications of meteorology to plant and animal life. We know that any amount of dark heat alone will not enable most plants to grow in a normal healthy condition, and, again, Sir William Siemens has shown that, given proper supplies of dark heat, plants flourish and ripen under the rays of the electric arc, if, and only if, these rays are filtered through plain glass. Stokes, in 1859, showed that plain glass intercepts nearly all the actinic rays emitted by the electric light, whence Siemens concludes that an excess of these rays is not beneficial but destructive to plant life, and these are just the rays chiefly absorbed by the atmosphere—a fact strikingly illustrated by the researches of Crova, who has succeeded in photographing invisible clouds. We are, as yet, without sufficiently numerous photographic records of sunshine to discuss the practical bearings of this matter, if indeed the instruments in use are adapted to the purpose; but it deserves further investigation, particularly at high-level stations where the proportion of actinic rays is increased and the effect of direct sunshine on vegetation in all probability correspondingly altered.

We take, then, the term "bright sunshine" to mean a condition such that rays are transmitted through the atmosphere which are capable of producing heat effects exceeding a certain minimum intensity, a minimum determined by the circumstances of the instrument employed in record-

¹ *Quart. Jour., Royal Meteorological Society*, vol. xix. p. 91.

ing. The burning recorder of bright sunshine most commonly used is that known as the Campbell-Stokes. In December, 1854, Mr. J. F. Campbell of Islay erected on his house in Whitehall an apparatus consisting of a hollow sphere of glass filled with acidulated water, placed concentrically in a wooden bowl of such diameter that the sun's rays, passing through the glass, were brought to a focus on the concave surface of the bowl and left a charred trace thereon. The bowl being put in position on the shortest day, the trace was made near its upper margin, and as the sun attained greater elevation the record for each day was lower than that for the day preceding, the lowest point being reached at midsummer, when a new bowl became necessary. On the second bowl the daily trace began near the bottom, and gradually returned to the old position near the margin at the winter solstice. In 1857 a solid glass sphere was substituted for the hollow one, and the instrument remained in continuous operation for seventeen years. The records of the twenty years to 1874 have been discussed by Sir Henry Roscoe and Professor Balfour Stewart (*Proc. R. S.*, 1875, p. 581). In 1875, experiments were made at Kew Observatory which led to the wooden bowl being replaced by a strip of card held by clamps, and finally, in 1879, Sir G. G. Stokes devised the form of metal frame for supporting the card now in ordinary use. Continuous records with this form of instrument date from the year 1880, and the Meteorological Office has recently published the results for the ten years, 1881-90, for the British Isles. It may be well to note again that the instrument frequently fails to record when the sun is at very low altitudes, and *always* fails for at least a quarter of an hour after sunrise and before sunset.

In discussing sunshine records, it is in the first place necessary to distinguish the cases where allowance must be made for latitude from those where the actual duration merely is required. The total heat received directly at a station is a function chiefly of the length of time the sun shines, and of his altitude during that time; this quantity would naturally form the basis of calculation, and also, if we restrict ourselves severely to the merits, of comparison. But it is in general fairer, as well as more useful, to judge each station according to its opportunities, and to express the sunshine it receives as a percentage of the total possible under the supposition that the sky remained cloudless all day and every day. For the present we employ only such percentages.

Mr. R. H. Scott, F.R.S., Secretary of the Meteorological Council, draws the following conclusions from the ten years' observations in the British Isles just referred to:—

1. The sea coast receives more sunshine than the inland parts of the country.
2. The south and west coast stations, and especially the Channel Islands, are particularly favoured in almost all months of the year. Jersey is the only station recording in any month, on the mean of the ten years, an average of even one-half of its possible duration of sunshine; 52 per cent. was registered there in May and 55 per cent. in August. The highest figure for any other station was only 48 per cent.

Here we have obviously the effect of mountains. The prevailing westerly winds from the sea maintain a fairly uniform temperature until

some obstacle such as high land forces the current upwards, cooling the air by expansion, and causing the moisture to condense into cloud. After the watershed is crossed, the current, having deposited some of its moisture, redescends on the eastern plains, is warmed by compression and gradually dried; the atmosphere accordingly becomes clearer, and we find a marked, if irregular, increase of sunshine towards the eastern seaboard stated by Mr. Scott:—

4. The east coast of Great Britain, as represented by Aberdeen, Geldeston, and Hillington, is comparatively sunny. In the case of Aberdeen this is evidently due to the position of the observatory, with the high Braemar mountains on its western side.

These facts are well supported by Mr. Bayard's (*Quart. Jour. R. Met. Soc.*, 1892, p. 213) cloud statistics for the same period. Subtracting the mean percentage of cloud amount from 100 we get the average proportion of clear sky, and the greater number of stations shows strikingly the increased cloudiness over mountains or stations on the slopes of mountains, and the gradual clearing towards the east coast. Two causes, however, considerably mask the real effect, both due to the fact that the averages are deduced from single daily observations made at 9 A.M.: the afternoon cloud maximum, best developed inland, where the ascending currents produced by the warming of the earth's surface are strongest, is entirely missed; and undue prominence is given to the morning cloudiness which persists longest near the sea. Falmouth and Jersey, for example, have an average of 31 and 34 per cent. of clear sky at 9 A.M., the same as Cheadle and Macclesfield, although the two pairs of stations show very differently in the record of sunshine. The point is of some interest in showing in a rough manner the departure of cloudiness at 9 A.M. from the daily mean. Cloud observations at 3 P.M. would probably show a deviation almost as great on the other side.

Perhaps the most striking feature in the distribution of sunshine over the British Isles is the fact that, speaking generally, the greatest percentage of sunshine is attained in districts where the annual range of temperature is least. The annual means of sunshine for the second lustrum, 1886-90, give values agreeing with the ten years' average to within 2 per cent. at all places included in the latter series, and there are for the shorter period a considerable number of additional stations whose values we may fairly assume to be equally close to a ten years' average. Utilising these, we get a marked indication of an axis of minimum sunshine running north and south somewhat to the east of the watershed, corresponding to the axis of maximum range of temperature. Again, whenever a break is made in the main line of elevated land by a valley opening to the west coast, the higher percentage of sunshine found at the coast extends inland to the east, in the same way as the smaller annual range of temperature in the same regions. The most conspicuous example in both cases is the Bristol Channel and valley of the Severn, where the percentage scarcely falls below 30, and the excess is carried right across to the east coast. The south coast of England is in effect another instance of the same

thing. The percentage of sunshine, on the average of five years, is 36 at Falmouth and St. Leonard's; 35 at Plymouth, Rousdon, and Ventnor; and 34 at Southampton, while 30 per cent. only is recorded at stations a short distance from the coast, as Glynde, Harestock (32), and Cullompton. The sunshine gradient, as it were, becomes steeper towards the land the farther east we go, and the annual range of temperature increases in exactly similar fashion.

In the absence of more detailed information, it is of course impossible to make the above statements in any absolute sense, or, indeed, to regard them as more than a slight extension of the general conclusion that "the sea-coast receives more sunshine than the inland parts of the country," in its application to our much more accurate knowledge of the distribution of temperature. They may serve, however, to show again how completely the climate of the British Isles is controlled by the sea; for in those places where the amount of sunshine is greatest, the range of temperature, its direct effect, is least; and the direct radiation effect is most apparent where the actual sunshine is least, *i.e.* where the influence of the sea is to some extent diminished.

For purposes of illustration merely, we may, within certain narrow geographical limits, and including the whole year, assume that the duration of sunshine at a station is a rough measure of the heat transmitted to it and from it by radiation through the atmosphere, since the cases where nocturnal radiation is checked will be to some extent compensated by the formation of cumulus clouds obscuring the afternoon sun; and we may further assume that the annual range of air temperature is an equally rough measure of the effect of such radiation on the lowest stratum of the atmosphere. Hence, dividing the duration of sunshine by the range of temperature, the cause by its effect, we may arrive at a general notion of the power of the other influences which come into play—the smaller the quotient the greater the immediate effect of radiation on the air temperature, and conversely. With the exception of the most northerly and westerly stations, and of those which come under the heading of smoky cities, the chief external influence is, as we have seen, the sea; and the numbers following, calculated by the method just described, give, to what may be called an illustrative approximation, the proportion of oceanic to continental constituents in the insular mixture of climates:—

Sandwich, . . . 67	Dublin, . . . 77	St. Ann's Head, . . 96
Stornoway, . . . 77	Worksop, . . . 51	Cirencester, . . . 62
Aberdeen, . . . 70	Parsonstown, . . . 68	Greenwich, . . . 49
Glasgow, . . . 53	Hillington, . . . 60	Kew, . . . 70
Armagh, . . . 61	Geldeston, . . . 67	Southampton, . . . 72
Markree, . . . 68	Cambridge, . . . 59	Glynde, . . . 63
Douglas, . . . 92	Aspley Guise, . . . 56	Falmouth, . . . 93
York, . . . 53	Valentia, . . . 99	Jersey, . . . 88
Stonyhurst, . . . 59	Oxford, . . . 58	Churchstoke, . . . 62

The variations in the distribution of sunshine from month to month during the year show some interesting peculiarities. In *January* the coast stations show out well with 20 to 25 per cent., the Midland and

North of England—apart from the large towns—giving 11 to 15 per cent. Then follow three months of steady increase, 20 to 30 per cent. in *February*, 30 to 40 in *March*, and 40 to 45 in *April*. *May* is in most places the sunniest month, although hard pressed by *August*. Jersey comes first with 52 per cent., the south coast of England averages about 45, and the Midlands and North 35 to 40. *June* and *July* show a distinct decrease, particularly at the north-western and extreme northern stations. *August* is "particularly sunny for Central and Southern England, and particularly sunless in the north-west of Ireland and of Scotland." The south coast again averages about 45, Midlands and North about 33, and the far north-west 25 to 28. *September* shows smaller percentages all round, the north-western districts maintaining their low position. In *October*, with a further general decrease, the Irish stations show some relative improvement, and in *November* they rank amongst the sunniest. *December* is the most sunless month of the year; Jersey heads the list with only 23 per cent.

It is difficult to say how far any of the records represent purely meteorological phenomena, and how far they indicate the pollution of the atmosphere by the smoke of cities and towns. Certain it is that Bunhill Row, with its 2 per cent. in *December*, 4 per cent. in *January*, and 9 per cent. in *February*, is very largely affected by smoke, and the same is also apparent in Glasgow and other manufacturing towns. The transition stages to air in which the suspended matter is derived from natural sources alone, such as is to be met with in the open sea, offer an interesting subject for investigation, particularly with regard to the classification of different types of fogs and mists.

The autumn sunshine of Ireland and the west and north-west of Scotland, about which Mr. Scott says:—

5. In the summer and early autumn the north-west of Ireland and of Scotland with the Orkneys receive very little sunshine.
6. In the late autumn Ireland generally receives more sunshine than most of England.

may be in part accounted for by a reference to Van Bebbber's monthly charts of cyclone tracks. During *September* and *October* these districts lie either directly on the line of main routes followed by depressions approaching from the Atlantic, or slightly to the right of them, in the direction of greatest humidity. One of these main routes, crossing the north of England, further accounts for the relatively low sunshine there. The south coast of England lies during these months to the left of a main track up-channel, which in *November* shifts northward, thereby increasing the cloudiness, especially to the eastward, and at the same time a subsidiary path branches south-eastward across the Bay of St. Malo—probably the cause of increased south-easterly winds in Jersey, which may explain the anomalous deficiency of sunshine there during that month. Again, the track lying directly across Ireland during *September* and part of *October* moves southward into St. George's Channel during *November* and leaves Ireland entirely clear—hence probably the increased sunshine there in early winter. The influence of these cyclone tracks is

of course most marked during the winter months, when they are most frequented, and the effects of elevated land must be taken as superposed upon those of cyclones. It is interesting in this connection to note the results of the investigations of the late Mr. Whipple at Kew, and more recently of Mr. Ellis at Greenwich, on the relation between sunshine and amount of cloud and the height of the barometer. These show that in the months from February to October there is on the whole distinct indication of increased sunshine and correspondingly less cloud with increased barometric pressure. This effect is less pronounced in early spring and late autumn, and becomes slightly reversed in winter. The diminished sunshine with high pressure in winter is, of course, the result of the cold fogs accompanying anticyclones, and the maximum sunshine occurs with intermediate pressures, probably chiefly in rear of depressions, the lowest pressures being associated with the overcast sky of a cyclone front and trough. It may be observed as a point of possible importance to hill farmers that the decrease of sunshine with winter anticyclones probably does not occur on peaks or any elevation not in the form of a table-land, the cold and fog being limited to low-lying districts, valleys, and plains.

The general form of the sunshine curve is thus a strong minimum in winter, a steady increase to a maximum in *May*, a secondary minimum in *June* and *July*, and another maximum in *August*, succeeded by a fall to the winter minimum. The uniform increase of sunshine percentage during spring occurs at all stations, but important modifications take place thereafter, which may be briefly summarised by saying that the *May* maximum predominates in the north and the *August* maximum in the south, and that the transition from one form to the other takes place gradually. The weakening of the *August* maximum in the west and north is, however, much more serious than that of the *May* maximum in the south. The occurrence of the former is barely noticeable except as a flattening of the curve, and even at York, Stonyhurst, and Douglas there is no actual increase from *July* to *August*, but at Southampton, Falmouth, and Jersey, where the *August* maximum is strongest, it scarcely exceeds that of *May*. The ten years' observations are insufficient to give very definite information with reference to the form of the intermediate minimum; it is impossible to fix the actual date of its occurrence in *June* or *July*. One point, however, is quite clear,—that the extent of the depression is greater near the coast than inland. At Oxford and Cambridge, for example, the mean percentage for *June* and *July* is only about 3 below that of *May*, while such stations as Jersey, Falmouth, Hillington, St. Ann's, and Douglas show a fall of 6 per cent. or more. It is noteworthy also that the curve for smoky cities closely approximates in form to the typical inland curve; Bunhill Row takes almost the same form as Oxford and Cambridge, with a mean some 10 per cent. less, and the inflection to the winter minimum somewhat sharpened.

For the practical ends of agriculture and similar industries the average distribution of sunshine from month to month is specially important as an estimate of probability. Given a certain average duration

of sunshine to the yearly credit of a particular district, how much is spent in the early part of the season, and how much is likely to be left over at the end of summer for the ripening of crops, when from other causes the harvest is late? The following table gives the fraction of the whole year's average sunshine, which is on the average recorded up to the last day of each month :—

TEN YEARS' SUNSHINE.

Per cent. of annual total received up to end of each month.

Station.	Jan.	Feb.	Mar.	April	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Sandwich, . . .	3	7	14	27	43	57	71	81	90	95	98	100
Stornoway, . . .	2	7	15	27	42	57	69	79	87	94	98	100
Aberdeen, . . .	4	9	17	27	41	55	67	78	87	93	97	100
Glasgow, . . .	2	6	14	26	41	56	69	81	90	96	99	100
Armagh, . . .	3	8	16	27	43	57	68	78	86	92	97	100
Markree, . . .	3	8	16	29	44	57	68	78	86	93	97	100
Douglas, . . .	3	7	15	26	41	55	67	78	87	93	97	100
York, . . .	2	7	15	25	40	55	67	80	88	95	98	100
Stonyhurst, . . .	2	7	14	25	40	54	67	79	88	94	98	100
Dublin, . . .	4	8	16	27	42	54	65	76	85	92	97	100
Worksop, . . .	3	7	15	25	40	52	65	78	87	93	97	100
Parsonstown, . . .	4	9	17	29	42	55	66	77	85	92	97	100
Geldeston, . . .	3	8	15	25	39	53	65	77	86	93	97	100
Hillington, . . .	3	8	15	25	40	53	67	79	87	94	97	100
Cambridge, . . .	3	7	15	25	39	52	65	77	86	94	97	100
Aspley Guise, . . .	3	8	15	25	38	51	64	76	86	93	97	100
Valentia, . . .	4	9	18	29	43	57	67	78	86	93	97	100
Oxford, . . .	3	7	15	25	38	51	65	77	86	94	97	100
St. Ann's, . . .	3	7	15	27	40	54	66	79	88	94	97	100
Cirencester, . . .	3	8	16	26	39	52	66	78	87	93	97	100
Bunhill Row, . . .	1	3	9	20	36	50	68	83	92	98	100	100
Greenwich, . . .	2	6	13	24	39	53	67	80	89	95	98	100
Kew, . . .	3	6	14	24	38	51	65	78	87	94	97	100
Southampton, . . .	3	7	15	25	38	51	64	77	86	94	97	100
Glynde, . . .	3	7	15	25	39	52	65	78	87	94	97	100
Southbourne, . . .	3	8	15	25	38	51	65	78	86	93	97	100
Falmouth, . . .	3	7	15	26	39	52	65	77	86	93	97	100
Jersey, . . .	4	8	16	26	39	52	64	77	87	94	97	100
Churchstoke, . . .	3	8	15	26	39	52	65	78	87	93	97	100

It appears that by the end of *January* the northern and inland stations have got through 2 to 3 per cent. of the whole sunshine; coast and southern stations 3 to 4 per cent. At the end of *February* the same districts have expended about 7 and 8 to 9 per cent. respectively, and at the end of *March* 14 to 15 and 15 to 16. In *April*, positions become slightly reversed; this is an exceptionally sunny month in the north and west, and the curves for these regions are bulged forward, rounding off the *May* maximum; and they show 27 to 29 per cent. of the total sunshine spent by the end of the month, while the other stations have still three-quarters of the whole left. *May* accentuates the differences with 40 to 43 and 38 to 39 per cent., and *June* and *July* bring the matter to a climax, when the southern and inland stations have 5 to 6 per cent. more of the whole sunshine still to come than those in the north and

west. The advantage gained is, for the most part, lost in making up the *August* maximum, and at the end of *September* nearly all stations have only about 14 per cent. remaining.

The limited nature of the information conveyed makes it useless to attempt any more rigorous treatment, for which, even when heat effects are alone concerned, it is absolutely essential to have some quantitative estimate of intensity. The real importance of sunshine in determining the temperature of the air at a particular station has been fully discussed in the investigations of Zenker (for a part of whose results see admirable abstract in *S.G.M.*, 1893, p. 193). In strictly continental climates, where the transference of heat by the winds is relatively small, the whole scale of temperature changes is a record of heat received from the sun and radiated back into space. But in insular climates the temperature is largely controlled by sea winds, and the effects of direct sun heat are superposed upon those of transferred heat. Hence it would follow that the direct heat effect of the sun is thrown into the background relatively to the light and chemical effects, for these are not affected by transference. Vegetation in climates like that of Britain is accordingly under conditions similar to that of a greenhouse; it is, as it were, artificially warmed from without, while it depends wholly on natural sunshine for supplies of light and chemical energy. In his *Géographie botanique raisonnée*, A. de Candolle, dealing with the amount of accumulated heat necessary for the maturation of plants, finds that certain species, notably *Alyssum*, require a greater aggregate when growing in insular places than in continental. This would confirm the view that in the former case the required sum of heat was made up from outside in a greater degree than in the latter, so that with the same number of assumed heat units, there remained a deficiency of light and chemical energy, in making up which the sun added on the excess of heat. To put it otherwise, we may imagine that rays of a certain wavelength, presumably those most copiously sent forth by the sun, are chiefly useful for the operations of plant life, and any alteration to less useful rays must be compensated by a more liberal supply. In the present deadlock between botany and meteorology the matter certainly demands full investigation.