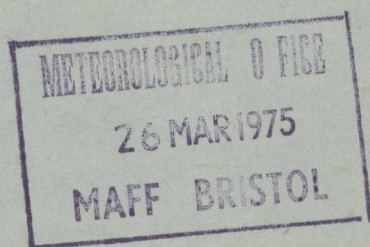


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REFLECTIONS ON SOME UNUSUAL YEARS

By J. M. CRADDOCK and M. J. WELLER

Summary. An analysis of the Lamb weather types for the years 1861–1970 suggests that although in most years the frequencies of the various types show only chance deviations from the long-term averages, the year 1872 and perhaps a few others deviate from the mean pattern in ways which are unlikely to arise by chance. The probability of occurrence of unusual years in future is discussed with reference to various rainfall records, and the suggestion is made that deviations of the general atmospheric circulation may operate to produce years about as wet as 1872 on average about once in 120 years.

Introduction. Although climate, and climatic changes, are usually discussed in terms of the values of meteorological elements averaged over periods of years, there are many applications in which the most useful climatic information is an estimate of the probability that some more or less extreme value will be exceeded. If past observations of the same kind can be fitted within reasonable limits of confidence by a suitable statistical distribution, then inferences may be made as to the probability of future extreme values, on the assumption that future values will conform to the same distribution, and this has often been done in the past. However, if the statistical distribution which covers most of the observations cannot be made to fit a few exceptional cases, then there is no reason to suppose that the distribution will be any more successful in estimating the probability of future extremes than it is in describing past observations. This article suggests that the probability of future occurrence of some of these unusual cases can be estimated only from the unusual cases themselves, and not from the statistics which describe the majority of past observations.

Inferences from Lamb's classification of daily weather types. The classification published by Lamb,¹ which now includes the years 1861 to 1970, is a revision of much earlier work on the same subject, in which every year has been treated by Professor H. H. Lamb in person, the years being taken in random order to minimize the risk of any unconscious change in standards during the months spent on the exercise. The detailed categories are grouped into the seven main weather types, which are used in the present analysis to describe the weather pattern each day within about a 10-degree square which includes the British Isles. Classifying the weather for a year involves looking at a sequence of at least 365 charts, one for each day, and observing the characteristic wind directions, motion of depressions, etc., and although opinions

may differ about the correct classification of an individual day, it is unlikely that another experienced synoptic meteorologist who repeated the work for a year would arrive at a significantly different result. A few days, averaging about 13 per year, are unclassifiable, and the mean frequencies of the seven types in the 110 years are shown in Table I. These means, which include virtually all the evidence on the subject which now exists, are the best estimates which can be made of the frequencies to be expected during an individual year.

TABLE I—FREQUENCIES OF LAMB’S DAILY WEATHER TYPES, WITH VALUES OF χ^2 , FOR SELECTED YEARS BETWEEN 1861 AND 1970

Year	W	NW	S	E	N	AC	C	χ^2
Mean*	93	18	27	28	31	91	64	—
1873	94	18	27	31	25	85	70	2.96
1953	100	16	23	18	28	119	49	18.58
1968	64	12	32	42	32	95	64	18.96
1877	115	29	20	26	27	56	81	32.55
1952	75	32	48	30	23	87	59	32.61
1887	73	19	43	22	19	124	51	34.09
1960	76	5	36	42	35	67	86	35.65
1921	124	8	17	18	32	113	42	36.39
1955	74	8	46	30	33	119	44	37.60
1923	129	28	31	25	26	52	66	37.68
1947	85	13	15	56	35	91	52	37.75
1924	94	16	16	23	54	66	89	40.06
1963	70	21	20	58	32	72	72	45.19
1872	101	15	29	26	45	38	100	58.64

AC Anticyclonic C Cyclonic * 1861–1970 inclusive

The expression $\chi^2 = \Sigma (O - E)^2/E$, where E is the long-term average, O the observed frequency, and the summation is over the seven categories, known as the chi-square statistic, is a common-sense measure of the extent to which the frequencies in any year differ on the average. Values of χ^2 are given in the last column of Table I for a year which closely resembles the average, two from the middle of the distribution, and for the 11 years among the 110 for which χ^2 is largest. If the annual rainfall for these 11 years is taken from the table of rainfall totals for England and Wales, published by Glasspoole,² and in an up-to-date form by Wales-Smith³ it appears that four of these years were very wet, two were very dry, and the rest not obviously exceptional. Average frequencies for these subgroups of years are given in Table II.

TABLE II—AVERAGE FREQUENCIES OF THE LAMB WEATHER TYPES FOR THE YEARS WHICH DIVERGE MOST FROM THE LONG-TERM MEAN, GROUPED ACCORDING TO THEIR ANNUAL RAINFALL TOTALS

	W	NW	S	E	N	AC	C
Long-term mean	93	18	27	28	31	91	64
Wet years 1872, 1877, 1924 and 1960	96.5	16.25	25.25	29.25	40.25	56.75	89.0
Dry years 1887 and 1921	98.5	13.5	30.0	20.0	25.5	116.5	46.5
Middling years 1923, 1947, 1952, 1955 and 1963	86.6	20.4	32.0	39.8	29.8	84.2	59.2

Table II shows that the wet years are characterized by excessive frequencies of the Northerly and Cyclonic weather types, and a deficiency of the Anticyclonic type. The dry years show excessive frequencies of the Anticyclonic weather type, and deficiencies in the Northerly and Cyclonic types, while the middling years, if they show anything, show an excess of the Easterly weather type which is in fact due entirely to the two years 1947 and 1963. Otherwise the frequencies, even though the years were chosen for their divergence from the average pattern, seem to conform surprisingly well to it.

Conversely, the other years in the rainfall record for England and Wales which had equally extreme rainfall totals also had high values for χ^2 , though not quite as high as those listed. This is strong evidence for an association between extreme values of the annual rainfall total in England and Wales and large departures of the frequencies of the Lamb weather types during the year from the long-term average, and of the two variables, the frequencies of weather types, though less familiar, are nearer to the general atmospheric circulation which produces them.

Estimating the 'equivalent number of repetitions'. The use of the chi-square statistic as a measure of the discrepancy between observation and expectancy suggests the question 'Do the 110 values of χ^2 fall into the distribution of chi-square with six degrees of freedom, as they should do if the 365 events sorted into seven categories were all independent?' The answer is that they do not do so, and the reason seems to be that the weather types which occur on successive days are not independent. This has the result of inflating the values found for χ^2 , and it may be possible, following Lewis and McIntosh⁴ to divide all the observed values of χ^2 by an 'equivalent number of repetitions' which brings the modified observations into agreement with expectation. This is done, using several trial factors, in Table III.

Table III suggests that the 'equivalent number of repetitions' is about 2.85, but the choice is not very critical. This factor has the effect of bringing the reduced values of χ^2 into satisfactory agreement with the distribution. Larger values of the factor produce an excess of years which conform too closely to the average, which is a common sign of overfitting, while smaller values produce larger numbers of deviant years. The factor 2.85 produces a small excess of large discrepancies, of which only one is individually significant, that for 1872. The observed value of χ^2 of 58.64, when divided by 2.85, has a probability of chance occurrence of only about 0.001. If this value is in fact due to chance, if, so to speak, the year 1872 is an ordinary member of the weather pack, it is rather surprising to find it in the sample of 110 years investigated. However, there is the possibility that 1872 is *not* an ordinary member of the weather pack, but a kind of joker, produced by some vagary of the general atmospheric circulation with a probability of something between about 1/55 and 1/220, in which case its occurrence once in 110 years is perfectly natural. Before trying to decide between these alternatives, it is worth while considering some other evidence.

Discussions of the annual rainfall at Bidston. The annual rainfall totals recorded at the Liverpool Tidal Observatory at Bidston for the years 1871 to 1930 were discussed by Doodson and Bigelstone⁵ in a paper which is remarkable for the way in which the senior author, Dr Doodson, treated his observations

TABLE III—AGREEMENT OF CORRECTED χ^2 WITH DISTRIBUTION OF CHI-SQUARE WITH SIX DEGREES OF FREEDOM

Range	0.5	5-10	10-20	20-30	30-50	50-70	70-80	80-90	90-95	95-100	χ^2
Upper limit	1.635	2.304	3.070	3.828	5.348	7.231	8.558	10.645	12.592		
Expected	5.5	5.5	11	11	22	22	11	11	5.5	5.5	
Factors											
3.255	6	5	22	8	24	19	11	7	6	2	16.24
	0.05	0.05	11	0.82	0.18	0.41	0	1.45	0.05	2.23	
3.184	5	5	19	11	22	22	9	8	7	2	
	0.05	0.05	5.82	0	0	0	0.36	0.82	0.41	2.23	9.74
3.15	5	5	19	11	22	19	12	8	6	3	
	0.05	0.05	5.82	0	0	0.41	0.09	0.82	0.05	1.14	8.43
3.05	4	4	18	12	24	17	11	9	8	3	
	0.41	0.41	4.45	0.09	0.18	1.14	0	0.36	1.14	1.14	9.32
2.95	4	4	14	15	23	17	12	9	6	6	
	0.41	0.41	0.82	1.45	0.05	1.14	0.09	0.36	0.05	0.05	4.83
2.85	3	4	14	13	24	18	10	10	7	7	
	1.14	0.41	0.82	0.36	0.18	0.73	0.09	0.09	0.41	0.41	4.64
2.75	3	3	12	15	23	18	10	12	6	8	
	1.14	1.14	0.09	1.45	0.05	0.73	0.09	0.09	0.05	1.14	5.97
2.65	3	3	8	19	20	19	8	16	5	9	
	1.14	1.14	0.82	5.82	0.18	0.41	0.82	2.27	0.05	2.23	14.88

Note. x_1 - x_8 frequencies of modified χ^2 values.
 y_1 - y_8 contributions to χ^2 .

in a way reminiscent of an old-fashioned schoolmaster dealing with an unruly class, and after considerable discussion, continued to believe in the relevance of a statistical distribution which did not agree with the facts. Zoch⁶ made a somewhat less controversial analysis of the same data, while Reynolds⁷ considered the longer series of annual totals running from 1867 to 1951, and concludes that if these rainfall totals are assumed to belong to the normal frequency distribution, then the rainfall total observed in 1872 should occur only once in 16 500 years. He does not draw the conclusion, which follows from the principles in paragraph 20 of *Fisher's statistical methods for research workers*,⁸ that this is a good reason for thinking that the normal distribution is not a suitable one for describing these data, and nowhere in the discussions is there any mention of a point which will occur to any present-day hydrologist, namely, that Bidston is sited in a pronounced rain-shadow as regards rain areas approaching from the west, but has no such protection against rain from the north-west, or in cyclonic situations, such as were unusually frequent in 1872, so that anomalous rainfall of the kind observed is something which might well have been expected from a knowledge of the frequencies of the various weather types. The statistical discussions have some historical interest, as illustrations of the attitudes of scientists over the years, but the practical moral is surely that when faced with what seems an extraordinary occurrence, it is necessary to consider as many as possible of the relevant facts.

The incidence of heavy rainfall, considered as a rare event. Reynolds⁷ states that during the 85 years from 1867 to 1951 there were 106 days for which a rainfall total of over one inch was reported, which gives an annual average of 1.247 days of rain exceeding this limit. This average can be used, as in *Fisher's statistical methods for research workers*, paragraph 15, to estimate the number of years, among the 85, which may be expected to have 0, 1, 2 etc. days of heavy rain. These expected frequencies are given together with the observed frequencies reported by Reynolds⁷ in Table IV.

TABLE IV—OBSERVED AND EXPECTED FREQUENCIES OF YEARS HAVING THE GIVEN NUMBERS OF DAYS WITH RAIN TALLING OVER ONE INCH

Number of rainy days								Total
	0	1	2	3	4	5	6	
Observed	27	28	18	9	1 (1947)	1 (1877)	1 (1872)	85
Expected	24.4	30.5	19.0	7.9	2.5	0.6	0.1	

The agreement between expectation and observed values is very good, except that a year with six days with over one inch, which is the number found in 1872, should occur only once in 850 or so years. The general agreement is noteworthy, because the basic conditions for the validity of the Poisson distribution, that each day should be exposed to the same risk, and that the occurrence of the event on one day should not affect its probability on another, are only approximately satisfied when the risk concerned is that of having rainfall exceeding one inch. Indeed, Reynolds gives monthly frequencies which show that the risk is about constant during the months of July and August, and higher than the risk at other times of year, but it appears from Table IV that this is enough to bring all years except 1872 into very good agreement with the

distribution. Since, as mentioned already, in 1872 Bidston was exposed to an unusually high number of rain-bearing situations without the benefit of its usual orographic protection, an increased risk in that year is not surprising.

The evidence from ancient years. Another way of increasing the amount of evidence on unusual years is to look back at the years before 1861. There are at present no series of charts for these earlier years from which the frequencies of Lamb weather types can be found, although there are plenty of early records from which charts could be prepared.* However, there are monthly rainfall records going back more than 100 years before 1861. The first comprehensive collection of such records seems to have been made by Symons,⁹ but the best-known modern reduction is the series of England and Wales monthly rainfall published by Glasspoole,² of which the annual totals, brought up to date, have been republished by Wales-Smith,³ who has also published a homogenized series of monthly rainfall estimates, or observations, for Kew for the period 1697 to 1970.¹⁰ Manley¹¹ has published a similar series for Manchester for the period 1765 to 1971. The wettest and driest years during these periods, according to the three reductions, are given in Table V.

TABLE V—WETTEST AND DRIEST YEARS IN PERIODS STATED ACCORDING TO THE REDUCTIONS OF GLASSPOOLE, MANLEY AND WALES-SMITH

England and Wales Glasspoole ² 1727-1973		Manchester Manley ¹¹ 1765-1971		Kew (London) Wales-Smith ³ 1697-1970	
Wet	Dry	Wet	Dry	Wet	Dry
1872 50+	1738 26+	1792 53+	1780 26+	1903 38+	1699 16+
1852 49+	1750 26+	1872 51+	1788 26+	1824 36+	1743 16+
1768 46+	1864 26+	1789 49+	1844 26+	1821 34+	1840 16+
1960 46+	1887 26+	1954 47+	1855 26+	1852 34+	1864 16+
1903 45+	1780 25+	1787 46+	1902 26+	1841 33+	1723 14+
1841 44+	1743 24+	1823 46+	1904 26+	1879 33+	1731 13+
1848 44+	1921 24+	1836 46+	1937 26+	1915 32+	1714 12+
1877 44+	1741 23+	1877 46+	1941 26+	1927 32+	1921 12+
1882 44+	1788 23+	1768 45+	1955 26+	1768 31+	
1912 44+	1731 22+	1848 45+	1826 25+	1819 31+	
		1852 45+	1933 25+	1828 31+	
		1882 45+	1887 21+	1860 31+	
		1931 45+			

Note. Rainfall amounts are given in inches. 49+ implies in range 49.0 to 49.9.

Comparison between the three series shows that while 1872 seems to have been very wet in Lancashire, and in the area represented by Glasspoole's reduction, it was not outstandingly so in the London area. There are several similar instances. Bearing in mind how different regions of the country are affected by different large-scale weather types, the question arises whether Glasspoole was attempting too much in trying to provide figures typical of the country as a whole. He himself states that the estimates before 1815 are less reliable than those for later years, and if it is assumed, for example, that Glasspoole's estimates for years before 1800 are too low by about 10 per cent, then the year 1768 becomes a candidate for being the wettest ever. Apart from this, 1852 seems to have been a very wet year over the whole country. At Manchester, 1792 appears to be wetter than 1872. At the other end of the

* But now see: KINGTON, J. A.; *Met. Mag., London*, 104, 1975, pp. 33-52 and *Weather, London*, 30, 1975, pp. 21-24 (Editor).

scale, the very dry year at Manchester, 1887, would appear to be extremely improbable, if the internal evidence provided by Manley's reduction was all the evidence available, but the appropriate volume of *British Rainfall* shows it to have been a well-authenticated occurrence which was discussed at the time, and was produced, like many other similar events, by relatively small modifications of the general atmospheric circulation. It is, in our opinion, wrong to imply the extreme improbability of any event which has happened within a comparatively short period. When an event has happened only once within the rather short period covered by modern observations, there is real difficulty in estimating its probability of occurrence, and the only alternative to waiting—possibly for centuries—until it has had time to repeat itself, is to look backwards for any evidence which may be gleaned from earlier years.

The extent of early records. Table VI which is condensed from Symons⁹ gives a good idea of the amount of basic information which was known in his day, and although it applies specifically to rainfall records, shows the general increase of interest in meteorological topics from the seventeenth century onwards. Until about 1770, there was only a trickle of information, which, as Symons remarks, represents work carried out by first-class men, and which was enough to establish the broad facts about the conditions under which sensible rainfall and other measurements can be made. Before that time, an estimate, for example, of the monthly rainfall for England and Wales is suspect not only because of doubt as to exposures, etc., but also because of the shortage of information of any kind. For example, it is too much to expect the monthly rainfall measured in Rutland to provide much evidence about the actual rainfall in Devonshire, however good the instruments and the observer. After 1770 there is a great deal of information, much of which has never been used, even now, because it is awkwardly placed, hidden in libraries, or in manuscripts which cannot easily be copied or collated.

Symons⁹ provides enough details of the stations known to him for each year from 1697 onwards. Glasspoole² only gives, for each year, the number of stations used in his reduction. These stations are usually rather more numerous than those which were known to Symons. However, the collection of copies of ancient records within the Meteorological Office has continued over the years, and the 10-year books, as they are called, which are held by the Agriculture and Hydrometeorology Branch of the Meteorological Office, now contain considerably more ancient data than were known to Glasspoole. The entries are undated, and usually give some reference to the source, but none to the copier, so that there is no way of making sure which records were available to which workers. However, it appears that further reductions, like those of Manley¹¹ and Wales-Smith³ are possible for other areas, such as the east Midlands, Devonshire and the Carlisle area. If, as the records suggest, Glasspoole had to rely on stations in the eastern half of England for almost all his estimates before 1780, this is a good reason for caution in using the earlier part of the monthly rainfall record for England and Wales.

Discussion. The analysis of the observed frequencies of the seven main Lamb weather types during the years 1861 to 1970 suggests that most years conform within statistical limits to the mean pattern, given an 'equivalent number of repetitions' of about 2.85, and that most of the minority of years which

TABLE VI—ANALYSIS OF RAINFALL RECORDS KNOWN TO SYMONS⁹ FOR STATIONS IN GREAT BRITAIN

Period	Number of station-years	Period	Number of station-years
Up to 1679	3	1770-1779	84
1680-1689	8	1780-1789	133
1690-1699	10	1790-1799	176
1700-1709	14	1800-1809	151
1710-1719	7	1810-1819	209
1720-1729	8	1820-1829	401
1730-1739	36	1830-1839	1 029
1740-1749	11	1840-1849	1 777
1750-1759	20	1850-1859	3 663
1760-1769	39	1860-1864	3 693

do not conform give rise to weather which is unusual in some way, particularly as regards rainfall. The use of the Poisson distribution on the numbers of years with from 0 up to 6 days with rainfall exceeding a threshold value confirms the suggestion that the year 1872 stands out from the rest among Reynolds's Bidston data. This is a technique for finding unusual years which might well be used more widely, since it is very easy to apply. Comparison of the reduction of long-period values of annual rainfall published by Glasspoole,² Manley¹¹ and Wales-Smith³ shows that there are considerable regional differences, but also that at least two other years since 1727, namely 1768 and 1852 rival 1872 in being very wet over a large part of the country. If these were associated with departures of the frequencies of the Lamb weather types from the 110-year averages comparable with the departures observed in 1872, the inference would be that the general circulation is liable to produce deviations of this size about once in 120 years. To the criticism that we cannot be sure about the character of the weather types in those early years, the answer is that we can at least try to appraise the evidence which exists. There may be no resources to carry out a systematic analysis of data for *all* years in the instrumental era before 1861, but it may still be worth while examining the outstanding years, which may throw some light on the probabilities of extreme conditions in future. The long-period records published by Manley and Wales-Smith, which refer to limited areas which may be expected to respond in much the same way in any given weather situation, agree better with the present thinking than Glasspoole's reduction, in which the basic data are weighted towards different areas in different epochs. The question whether the apparent climatic change in Glasspoole's data, between drier years in the 1700s and wetter years since, is real, or a product either of a statistical accident, or of imperfect reductions of the early data, lies outside the scope of this paper, but may well be answered by new statistical methods, and extra data, which have become available since Glasspoole's publication. A general conclusion is that until more is known of the capabilities of the general atmospheric circulation in imposing local weather regimes, either by mathematical modelling, or by examining data from the earlier part of the instrumental record, it will remain hazardous to attempt, by statistical means, to estimate the probabilities of extremes which have not occurred during the period of full observations.

REFERENCES

1. LAMB, H. H.; British Isles weather types and a register of the daily sequence of circulation patterns, 1861-1971. *Geophys Mem, London*, 16, 1972, No. 116.
2. GLASSPOOLE, J.; Two centuries of rain. *Met Mag, London*, 63, 1928, pp. 1-6.
3. WALES-SMITH, B. G.; Monthly and annual totals of rainfall representative of Kew, Surrey, from 1697 to 1970. *Met Mag, London*, 100, 1971, pp. 345-362.
4. LEWIS, R. P. W. and MCINTOSH, D. H.; Some effects of the coherence of meteorological time-series. *Met Mag, London*, 87, 1952, pp. 242-244.
5. DOODSON, A. T. and BIGELSTONE, H. J.; The frequency distribution of rainfall at Liverpool Observatory, Bidston. *Q J R Met Soc, London*, 60, 1934, pp. 403-411.
6. ZOCH, R. T.; On the frequency distribution of rainfall at the Liverpool Observatory. *Q J R Met Soc, London*, 62, 1936, pp. 421-433.
7. REYNOLDS, G.; Rainfall at Bidston, 1867-1951. *Q J R Met Soc, London*, 79, 1953, pp. 137-149.
8. FISHER, R. A.; Statistical methods for research workers, 10th edition. London, Oliver and Boyd, 1954.
9. SYMONS, G. J.; An outline sketch of rainfall investigations from A.D. 1677 to A.D. 1865. *Rep Brit Assn Advanc Sci*, 1865, London, 1866.
10. WALES-SMITH, B. G.; An analysis of monthly rainfall totals representative of Kew, Surrey from 1697 to 1970. *Met Mag, London*, 102, 1973, pp. 157-171.
11. MANLEY, G.; Manchester rainfall since 1765. *Mem Proc Manchester Lit Phil Soc, Manchester*, 114, 1972, pp. 70-89.

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PRELIMINARY RESULTS FROM A GRAVIMETRIC RAIN-GAUGE

By H. E. PAINTER

Summary. Rain recorded by a gravimetric rain-gauge has been measured and compared with the daily amounts collected in a standard 5-inch Mk 2 gauge with its rim 30 cm above the ground, in two types of gauge with their rims flush with the ground, and in a 750-cm² gauge with its rim 45 cm above the ground and fitted with a tipping-bucket mechanism. The relative inefficiencies of these gauges compared with the gravimetric gauge are clearly shown and corrections for daily rainfall amounts are given for these various types of gauge.

Introduction. The amount of rainfall collected by the conventional type of rain-gauge is generally less than the actual rainfall at the site of the gauge; this effect arises from various causes such as evaporation, adhesion of rain to the gauge, in-splash and out-splash, but by far the greatest factor is that due to the exposure to the wind, which generally causes a bigger error than all the other causes combined, see for example Kurtyka.¹ Various attempts have been made to eliminate or reduce the effect of the wind on the catch of a gauge. One such method is to mount the gauge with its rim level with the ground and to surround it with an artificial surface to minimize the effect of in-splash. Gauges mounted like this together with their surrounding surfaces can, however, still cause wind eddies which affect their catches. Even if everything else were perfect the hole in the ground made by the collecting funnel would be enough to change the wind flow over the surface of the ground. As part of a programme carried out by the Meteorological Office to assess the performance of rain-gauges, a recording gravimetric rain-gauge was developed and installed at Kew Observatory. This instrument has been described by Crawford² and now that a considerable amount of data has been obtained from it, the results of comparisons of simultaneous rainfall measurements from various gauges are here presented.

Rain-gauges. The gravimetric rain-gauge has a 1.21-m diameter pan mounted on a weighing machine placed in a concrete pit in the ground so that the rim of the pan is level with the surrounding ground. About 2.5 cm below the rim of the pan is a stainless steel mesh covered by a layer of small granite chips. An annular area extending 2 m from the rain-gauge pan is also covered with granite chips so that this area and the pan form a homogeneous surface apart from a small gap between the pan and the concrete pit. The weighing machine automatically measures the weight of the pan and its contents; this weight is converted into a millivolt analogue which is registered on a recorder.

Six other gauges were used in this comparison. Three were standard 5-inch Mk 2 rain-gauges with their rims 30 cm above the ground. Two standard 5-inch Mk 2 gauges were also mounted with their rims flush with the ground; these will be referred to as 'flush gauges'. One of these was in a 23-cm deep square pit with sides of 120 cm in length which was covered with a plastic grid with squares of side 5 cm. The depth of the grid is 5 cm and its top surface is level with the rim of the gauge. The base of the pit is composed of small stone chippings. The top edges of the grid were chamfered on the sides farthest from the rain-gauge so that drops hitting these edges would be deflected away from the gauge. This gauge is of the type recommended by the World Meteorological Organization.³ The second flush gauge has a splash-reducing surround suggested by Bleasdale.⁴ This is an array of thin green metal slats as used in venetian blinds. These slats are fixed to radial bars projecting from just beyond the rim of the gauge out to a distance of 61 cm. The slats are inclined at 45° to the horizontal and are so placed that splashes will tend to be directed away from the gauge. Below the slats is a gravel bed so that when the rain runs off the slats it is drained away. Several accounts^{5,6} describe flush gauges with this type of splash-reducing surround, but with an array of nine gauges; for this comparison only one gauge was used.

The remaining rain-gauge was a Meteorological Office tipping-bucket gauge with a funnel made of glass-fibre laminate of area 750 cm² and with its rim 45 cm above the ground.

Two of the standard 5-inch gauges were used for the routine Observatory measurements of rain and were read twice daily at about 5 minutes before the nominal observing times, whether it was raining or not. The third standard 5-inch gauge together with the WMO flush gauge and the tipping-bucket gauge were installed especially for this comparison and were read once daily at about 09 GMT. If, however, it was raining the reading of these three gauges was deferred until the rain had stopped. Occasionally the readings were deferred for a whole day and so the amount of rainfall in the comparisons covered a period of two days. The venetian-blind flush gauge had been installed for some years and was used in connection with measurements of evaporation from tanks. This gauge was read when the evaporation readings were made, which was usually at about 10 GMT. If the rainfall was heavy at the nominal reading time these measurements were deferred. If there was rain whenever any of these rain-gauges were being read the exact time of the measurement was noted.

These gauges are in the grounds of the Observatory which itself is in flat open park-land. A detailed description of the site is given in the *Observatories' Year Book 1965*.⁷ To the north and north-west of the gravimetric gauge are shrubs and small buildings rising to about 6 m at a distance of about 30 m. The largest obstructions to the gauges are two trees rising to 30 m between bearings

of 190° and 210° from the gravimetric gauge at a distance of 100 m. Otherwise, apart from instruments, the site is clear. Table I gives the nominal times of reading of the various gauges and their locations with respect to the centre of the gravimetric rain-gauge, hereinafter abbreviated to GRG. The second column of the table gives abbreviated titles of the other gauges and these abbreviations will subsequently be used.

Measurements. Rain in the 5-inch gauges was measured in the usual way to the nearest 0.1 mm by pouring it into a graduated glass measure. The rain in the TB gauge was registered by an electromagnetic counter, each increment in the count corresponding to 0.202 mm of rain. A few readings from this gauge had to be discarded as they were obviously in error, and in addition the instrument was out of action for several days. The output of the GRG was recorded on a 10-inch wide strip-chart running at one inch an hour. For most of the period the full-scale range of the recorder was equivalent to 30 mm of rain. For the first three weeks of September 1972 the full-scale range was 50 mm; from 26 January to 21 May 1973 the full-scale range was 18.4 mm. The recorder registers the rain every minute. The chart is divided into 100 divisions and can be read to a tenth of a division. The sensitivity, the sampling time, and the chart speed can all be varied. The settings of these variables will determine the degree of discrimination and the accuracy to which rain, dew, evaporation from the pan, and the rate of rainfall can be measured. It will be seen that, for most of the period of this comparison, the gain and loss of water could be measured to within 0.03 mm.

The rain was measured for each hour GMT during which it occurred. No account was taken of evaporation which showed between rainfall events, i.e. only increases in weight were measured. (A 'rainfall event' signifies an occurrence such as an individual shower or period of frontal rain.) Since the times at which the other gauges were read were known the GRG was read at these precise times. This, of course, was only important if any of the other gauges were read while it was raining. Occasionally, when rain was recorded, dew also was recorded at other times of the day; this was always added to the rain amount since the funnel gauges also collect dew. Two days when moderate snow fell have been excluded from the analysis. Six days on which part of the catch was hail have been included. For this analysis comparisons were only made if the corresponding daily rainfall amount measured by the GRG was at least 1 mm. For gauge A the daily period was taken from 09 GMT; for gauge B the period was taken from 18 GMT; for both of these gauges daily rainfall values could include the aggregate of two readings.

Although a strict comparison was made between each gauge and the GRG, the rainfalls measured by the various gauges were not always derived from the same rainfall events because the measurements were taken at different times. The aggregates, however, over the whole period were approximately the same for most of the gauges. Readings were taken from September 1972 to February 1974. The GRG was not always operative throughout this period as it was removed at times to enable modifications to be carried out; in addition the record was lost several times because it went beyond the limits of the scale.

Gauge A was found to be 0.5 per cent over-size in area, and gauges C and WMOF were 0.2 per cent under-size. The aggregate totals were accordingly corrected, and individual daily readings of gauge A were corrected when they exceeded 10 mm.

The results of the comparisons are shown in Table II. The first part of this table gives the aggregate rain for all the daily values considered, i.e. when the GRG measured at least 1 mm of rain. Following the method of an earlier comparison of rain-gauges by Clarkson⁵ at Easthampstead near Bracknell, the daily variation of rainfall is given by the regression equation of \bar{Y} (the catch of the comparison gauge) on G (the catch of the GRG) for the various rain-gauges, together with the 95 per cent confidence limits of the regression. The most probable value of \bar{Y} for a 10-mm rainfall measured in the gravimetric gauge is given as a percentage ratio. The lower portion of the table gives the regression equations of \bar{Y} for gauges A and TB on the 5-inch standard gauge C, these being directly comparable with gauges compared by Clarkson.⁵ In order to compare the readings of the two 5-inch gauges a selection had to be made so as to restrict the number of days on which both gauges were measuring the same rainfall irrespective of the different times of day at which they were read.

Reference rain-gauge. When the results from two instruments simultaneously measuring the same element are compared all that can be assessed is the performance of one relative to that of the other. If one instrument is used as a reference it is required that its accuracy be within acceptable limits. The GRG has been developed as a reference rain-gauge as suggested by Crawford.² Although it is difficult, if not impossible, to demonstrate that any rain-gauge actually measures the amount of rain that would have fallen on the ground in the absence of the gauge, the author considers that, for the GRG, the factors which are known to give rise to the errors of conventional types of gauge have been considerably reduced. The construction of the collecting area of the GRG together with its surrounds has been designed to affect the airflow over the instrument as little as possible, and also to minimize the net effect of splashing. As mentioned earlier the exposure of the conventional gauge has been the source of its biggest errors, and as will be shown later even mounting funnel gauges flush with the ground fails to eliminate all errors due to exposure. By the construction of the GRG, its catch must be less affected by the wind than that of the other types considered here. Even if there is an inequality between in-splash and out-splash in the GRG, the relatively large size of the pan will further reduce this effect upon rainfall measurements.

With regard to other sources of errors in rain-gauge measurements, adhesion of water to the instrument obviously has no effect on the GRG. Two forms of water exchange that affect rainfall measurements are demonstrated by the GRG: these are evaporation and the deposition of dew. Since any rain-gauge introduces an artificial object in the ground, the deposition of dew and the evaporation of water from a gauge will vary from instrument to instrument and will differ from what takes place on the neighbouring natural surface. A supplementary instrument or observation of 'weather' may be needed to determine whether a slight increase in weight of the GRG is caused by dew or by light rain. Generally these will not occur together so they can be isolated when one examines the GRG record. Evaporation from the pan is often recorded but this again can be isolated for periods when it is not raining, since the measurement of rain consists of the summation of the record when the weight is increasing. If evaporation occurs during rain the GRG measures the net increase in weight. Light rain has occasionally been observed when the GRG showed a continuing loss of weight. It is doubtful whether, in these circumstances, other gauges

TABLE I—DETAILS OF RAIN-GAUGES USED IN COMPARISON

Gauge	Abbreviated title	Area <i>cm</i> ²	Height of rim above surface <i>cm</i>	Approximate times of reading GMT	Distance <i>m</i>	Location with respect to GRG Bearing °
Gravimetric	GRG	115.0 × 10 ³	0	—	—	—
Standard Mk 2	A	126.7	30	0855, 2055	22.1	232
Standard Mk 2	B	126.7	30	0555, 1755	22.1	242
Standard Mk 2	C	126.7	30	0900	13.5	16
WMO flush	WMOF	126.7	90	0900	4.4	177
Venetian-blind flush	VF	126.7	0	1000	13.9	247
Tipping-bucket	TB	750	45	0900	13.4	5

TABLE II—VARIABILITY OF CATCH OF RAIN-GAUGES AT KEW FOR AGGREGATE TOTALS AND FOR DAILY RAINFALL AMOUNTS FOR WHICH THE GRAVIMETRIC GAUGE RECORDED AT LEAST 1 mm

Comparison gauge	<i>N</i>	Aggregate rainfall Comparison gauge <i>millimetres</i>	GRG	Percentage of catch of GRG	<i>E</i>	<i>P</i> <i>per cent</i>
5-inch standard A	101	461.0	495.3	93.1	$\bar{r} = 0.967 G - 0.167 \pm 0.506$	95.0 ± 5.1
5-inch standard B	100	440.8	475.5	92.7	$\bar{r} = 0.966 G - 0.191 \pm 0.529$	94.7 ± 5.3
5-inch standard C	92	436.8	474.6	92.0	$\bar{r} = 0.956 G - 0.194 \pm 0.420$	93.7 ± 4.2
WMOF	92	459.4	474.6	96.8	$\bar{r} = 0.993 G - 0.138 \pm 0.389$	97.9 ± 3.9
VF	100	477.8	486.3	98.2	$\bar{r} = 1.021 G - 0.193 \pm 0.502$	100.2 ± 5.0
TB	79	362.7	388.7	93.3	$\bar{r} = 0.951 G - 0.089 \pm 0.554$	94.2 ± 5.5
5-inch standard A	56	266.1	Gauge C	Percentage of catch of gauge C		
TB	78	359.9	263.8	100.9	$\bar{r} = 1.005 S + 0.050 \pm 0.387$	101.0 ± 3.9
			356.7	100.9	$\bar{r} = 0.985 S + 0.120 \pm 0.516$	99.7 ± 5.2

N Number of daily rainfalls each of which was recorded as at least 1 mm in the GRG.

G Amount collected in comparison gauge.

S Amount collected in GRG.

E Regression equation of \bar{r} on *G* (or *S*) for daily rainfalls, \pm the 95 per cent confidence limits of \bar{r} .

P Most probable percentage \bar{r}/G (or \bar{r}/S) \pm the 95 per cent confidence limits, for a rainfall of 10 mm in the GRG (or gauge C).

would have detected any precipitation. Evaporation, during rain, will occur from funnel gauges and also from natural surfaces, and from the hydrologist's point of view the net water gain may be more useful than the quantity of water from precipitation, but the meteorological definition of precipitation does not take into account any evaporation during precipitation. Any deficiency in the water catch during rain caused by evaporation will therefore cause an error in the GRG measurement. As is shown later all the other gauges on average produce deficits compared with the GRG and any error caused by evaporation from the GRG will enhance these deficits.

Although the errors of the GRG are not quantified the author considers that it will measure rainfall more accurately than the other gauges here described, and the GRG is therefore being used as a reference gauge to which the other gauges can be compared.

Discussion. It is seen from Table II that the three standard 5-inch gauges agree in their aggregate catches to within ± 0.6 per cent and that the 750-cm² gauge with a tipping bucket is in close agreement with the 5-inch gauges, as was previously found at Easthampstead.⁵ The scatter about the GRG measurements of the daily values derived from the two gauges A and B, which were used for routine observational purposes, was slightly greater than that of the daily values from gauge C but this would be accounted for by the fact that the values for A and B were often the aggregate of two measurements. For the same reason the comparison between two 5-inch standard gauges at Kew shows slightly more scatter than do the Easthampstead comparisons. One might have expected that the aggregate readings from gauges A and B would have been slightly lower than the corresponding readings from gauge C owing to losses when the former gauges were read during rain, and it therefore seems probable that any difference between these gauges is due either to slight differences of exposure or simply to experimental error. The WMOF gauge shows less scatter than the VF gauge, which can perhaps be attributed to their different splash-reducing surrounds. Alternatively, as discussed later, there is a possibility that the VF gauge is receiving some in-splash which would add another variable to the VF catch and so increase its scatter relative to that of the GRG. From Table II it is immediately obvious that all the gauges, including the flush gauges, are catching less rain than the GRG. The raised gauges collect in the aggregate about 7 per cent less rain, and the flush gauges about 2 to 3 per cent less than the GRG.

Gauge C is considered to be a typical 5-inch gauge with its rim at 30 cm, and the results of its comparison with the GRG are shown in Figure 1 where the ratio of the catch of the GRG to that of gauge C is plotted against the daily catch of gauge C. This figure represents the data used for the regression equation plotted in a form that emphasizes the differences at small daily rainfalls. Similar graphs were plotted for the two flush gauges and for the TB. These graphs showed similar scatter about their mean curves. In Figure 1 the values for which the precipitation included hail as well as rain have been plotted with distinguishing symbols. In all cases the hail was only a small part of each daily catch, and as can be seen from the plots they do not show any marked departure from the mean curve; hence these days have been included in the analysis.

Since the GRG is being used as a reference gauge the curve plotted in Figure 1 gives mean correction factors for daily rainfalls from gauge C. The

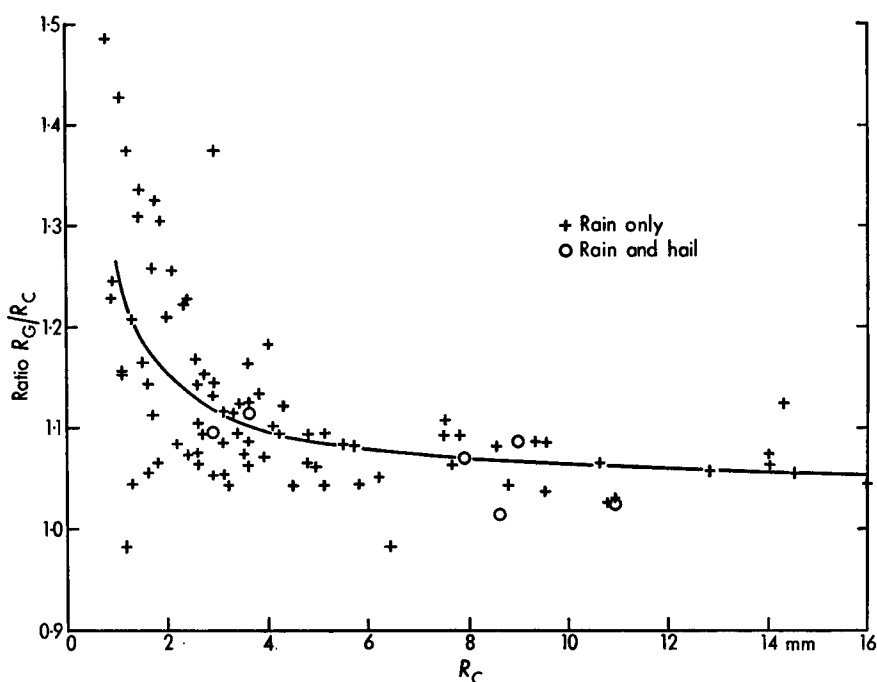


FIGURE 1—VARIATION OF RATIO (R_G/R_C) WITH R_C , WHERE R_G IS THE DAILY RAINFALL AS MEASURED BY THE GRAVIMETRIC RAIN-GAUGE (GRG), AND R_C IS THE DAILY RAINFALL AS MEASURED BY THE STANDARD GAUGE C

mean curves for each of the four types of gauge are shown in Figure 2. These curves are, in fact, the regression equations of the GRG on the comparison gauges plotted in the form appropriate to the axes chosen for Figures 1 and 2. By changing round the order of the regressions the equations now give mean correction factors for daily rainfalls for each of the comparison gauges. These equations for the four gauges together with their 95 per cent confidence limits are given in Table III in which R_x is the rainfall given by the comparison gauge and \bar{Y} is the corrected rainfall, i.e. that which would have been expected in the GRG.

TABLE III—CORRECTED DAILY RAINFALL (\bar{Y}) DERIVED FROM CATCHES OF VARIOUS GAUGES (R_x) WITH 95 PER CENT CONFIDENCE LIMITS

Gauges

5-inch standard	$\bar{Y} = 1.042 R_x + 0.220 \pm 0.436$
WMOF	$\bar{Y} = 1.005 R_x + 0.151 \pm 0.392$
VF	$\bar{Y} = 0.974 R_x + 0.211 \pm 0.485$
TB	$\bar{Y} = 1.045 R_x + 0.123 \pm 0.580$

Note. Measurements are expressed in millimetres.

The deficits in the rain catches of all these gauges compared with those of the GRG are immediately apparent from Figure 2. The two flush gauges and the standard 5-inch gauge at 30 cm are all of the same type and they each exhibit

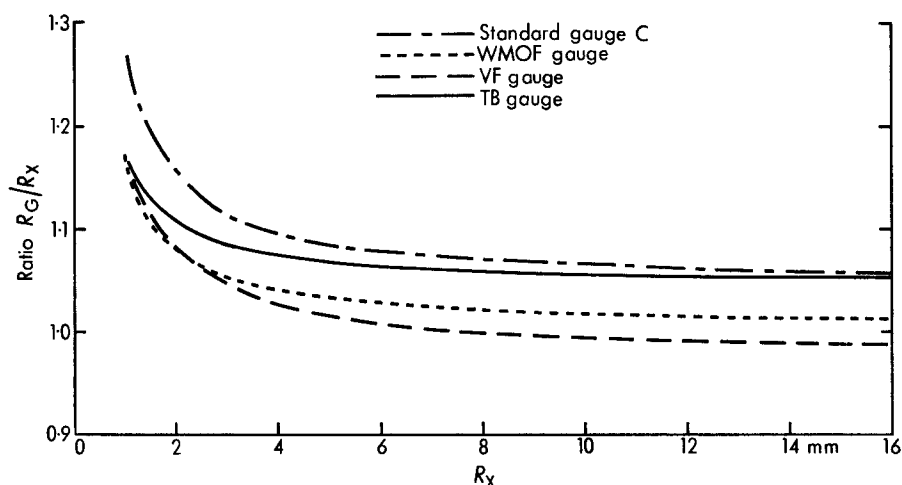


FIGURE 2—VARIATION OF RATIO (R_G/R_X) WITH R_X , WHERE R_G IS AS DEFINED IN CAPTION TO FIGURE 1, AND R_X IS THE DAILY RAINFALL AS MEASURED BY GAUGE X, WHERE X IS ONE OF THE FOLLOWING:

- (i) A STANDARD GAUGE (C)
- (ii) A WMO-RECOMMENDED GAUGE MOUNTED FLUSH WITH THE GROUND (WMOF)
- (iii) 'VENETIAN-BLIND' FLUSH-MOUNTED GAUGE (VF)
- (iv) A TIPPING-BUCKET GAUGE (TB)

the same shape of graph but with a displacement of 5 to 7 per cent between the values corresponding to the flush types and those corresponding to types with standard exposure. The range of values for the TB gauge is smaller than those of the other gauges, which perhaps can be attributed to the greater diameter of the funnel of this gauge. Especially noteworthy is the difference between the two flush gauges; whereas the WMOF shows a deficit over the whole range of rainfalls considered, the VF actually shows an increase in catch over the GRG at large daily rainfalls. As occasionally particles of sand, from the gravel bed below the slats, are found in the funnel, it is evident that there is a certain amount of in-splash which would account for this slight increase of the readings of the VF over those of the GRG. For daily rainfall values of 6 mm and over the VF agrees with the GRG to within ± 1 per cent. The other noteworthy feature of these graphs is the large deficiencies shown by all the comparison gauges for small daily amounts. This seems to offer strong evidence that the flush gauges are still subject to exposure errors. Two major factors which contribute to loss of rain in rain-gauges are the wind speed and the raindrop-size; smaller drops will be affected more than larger drops by the wind. The problem is complex because there will be varying drop-sizes in a particular rainfall and here we are considering daily rainfall amounts which can be composed of entirely different types of rain at different times during the daily period. The shape of the curves in Figure 2 suggests that when the daily rainfall is small it is mainly composed of small drops and that, as is to be expected, if a big rainfall is recorded there has been a preponderance of large raindrops.

The scatter in Figure 1 probably largely reflects the variability of the size of the rain drops. A small anemometer (kindly loaned by Imperial College, London) was mounted at a height of 1 m above the ground about 4 m south of the TB gauge. The anemometer output was recorded on the same chart as that of the GRG, and the mean wind speed was evaluated for each daily rain measurement. The anemometer was out of action for some of the time so there are fewer observations of wind than of rain. The wind speeds were plotted against the ratio of the daily rainfalls measured by the GRG to those measured by the comparison gauges. There was considerable scatter with apparently little correlation between the ratio of the catches and the wind speed. The large scatter and small correlation has been noted by other experimenters.^{6,8} The results obtained in the present investigation are shown in Table IV as regression equations, with their 95 per cent confidence limits.

TABLE IV—REGRESSION EQUATIONS OF CATCH RATIO (Q) AGAINST WIND SPEED (m/s) AT A HEIGHT OF 1 METRE (U)

Gauge	Regression
A	$Q = 1.114 + 0.058 U \pm 0.20$
WMOF	$Q = 1.073 - 0.005 U \pm 0.13$
VF	$Q = 1.087 - 0.014 U \pm 0.16$
TB	$Q = 1.070 + 0.009 U \pm 0.24$

These equations are obtained from observations with a large scatter and in only a few of the observations was the wind speed less than 1 m/s. The catch ratio should be unity when there is no wind, so these equations only represent the relationship between the catch ratio and the wind speed when the latter is greater than 1 m/s. Whether it is significant that the two flush gauges show the catch ratio getting smaller with increasing wind can hardly be determined from this evidence. That there is not a marked increase in the catch ratio with increasing wind speed must be because the rainfalls with greater wind speeds are composed of larger drops which are not so readily deflected from the rain-gauges. Of course, the wind at the flush gauges will be less than that at the two gauges exposed at heights of 30 and 45 cm above the ground and the regression equations refer to the wind speed at a height of 1 m. On the assumption that the drop-size of rain is directly proportional to the rate of rainfall, an attempt was made to relate the catch ratio of gauges to the drop-size by plotting the catch ratio against the mean daily rate of rainfall. These rates of rainfall were estimated from the GRG record. In the course of a day the rate of rainfall could vary over a very large range and these mean rates of rainfall can only be rough estimates. Here again there was a very big scatter of the points plotted for all the gauges, but the regression lines through the points all showed a slight decline in the ratio of the catch of the GRG to that of the comparison gauge with increasing rate of rainfall.

It has not therefore been possible to isolate the losses in rain-gauge catch or to apportion these losses to the effect of wind speed or of drop-size. In practice few stations would be able to measure these other variables and a correction to the daily totals in a standard gauge as given by the regression equation in Table III would be all that could be attempted.

The whole analysis obviously needs to be tested over a longer period and at other stations where stronger winds are experienced and different weather

conditions prevail. The GRG recorded perfectly during both hail and snow but it was considered that since snow fell on only two days no useful conclusions could be drawn from these snowfalls. More investigations are needed of the measurements of very small rainfalls when evaporation and, in funnel gauges, adhesion of the rain to the gauges, are likely to be of greater significance. Further data may modify some of the conclusions suggested here but it is considered that enough evidence has been produced to show that the performance of the GRG is considerably better than that of the other gauges used in this comparison even when they are mounted flush with the ground.

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REFERENCES

1. KURTYKA, J. C.; Precipitation measurements study. *Illinois St Wat Surv Div, Urbana, Rep No. 20*, 1953
2. CRAWFORD, S. G.; A recording gravimetric rain-gauge—towards an absolute instrument. *Met Mag, London*, **101**, 1972, pp. 368–374.
3. Geneva, World Meteorological Organization. Instructions for international comparisons of national precipitation gauges with a reference pit gauge. Geneva, 1971, Reference T/10P, Annex II. (Unpublished, copy available in Meteorological Office Library, Bracknell.)
4. BLEASDALE, A.; The measurement of rainfall. *Weather, London*, **14**, 1959, pp. 12–18.
5. CLARKSON, L. S.; On the performance of various types of rain-gauge in the field. *Met Mag, London*, **100**, 1971, pp. 241–255.
6. GREEN, M. J.; Effects of exposure on the catch of rain gauges. *Tech Pap Wat Res Assn, Medmenham*, No. 67, 1969.
7. London, Meteorological Office. *Observatories' Year Book* 1965. London, HMSO, 1968.
8. RODDA, J. C.; The rainfall measurement problem. Gentbrugge, International Association of Scientific Hydrology, *IASH Publ No. 78*, 1968, pp. 215–231.

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THE RELATIONSHIP BETWEEN MINIMUM TEMPERATURES OVER DIFFERENT GROUND SURFACES

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Summary. Minimum temperatures over concrete and bare-soil surfaces are examined in relation to the magnitude of the grass-minimum depression below the screen-minimum temperature. Regression equations, which enable the concrete and bare-soil minimum temperature to be forecast directly from the grass-minimum depression, are presented on a monthly and seasonal basis.

Introduction. The consequences of severe frost are of increasing economic importance, particularly to farmers, market gardeners and motorists. Accurate forecasts of the minimum temperatures over different ground surfaces are therefore even more essential now than they have been in the past.

The main factors which influence minimum temperatures near the surface of the ground are:

- (a) Outgoing radiation, which depends upon the nature and the temperature of the surface and also on the length of the cooling period.

- (b) Back radiation from the atmosphere, which depends on the height, amount and thickness of any cloud present, and also on the water-vapour content of the air.
- (c) Wind speed, which controls the depth of the mixing layer.

Other less important factors include the latent-heat exchange following any evaporation or condensation at the surface, and any conductive exchange of heat with adjacent layers of air or the ground.

These factors are taken into account in the standard methods of forecasting overnight minimum air temperatures due to Boyden,¹ McKenzie,² Saunders³ and others. Most outstations use a local refinement of one or other of these methods. Forecasts of the depression of the grass-minimum temperature below the screen-minimum temperature can be made by using other relationships found by Craddock and Pritchard⁴ and Saunders.⁵ More recently the interdependence between concrete and air-minimum temperatures (Parrey⁶ and Ritchie⁷) has been considered.

It is the intention of this note to consider the relationship between minimum temperatures recorded in the screen, and those over grass, concrete and bare-soil surfaces.

Data. Observations of the required minimum temperatures are recorded at Westbury-on-Trym (51°30'N, 2°37'W) near Bristol, from Monday to Friday each week. The period considered in this investigation was January 1972 to December 1973 which gave about 500 sets of observations. Minimum temperatures recorded during week-ends have been allocated to the night when the lowest air-minimum temperature as shown by the thermograph record occurred.

The concrete and bare-soil minimum thermometers were exposed horizontally with their bulbs in contact with the surface. The grass-minimum thermometer was exposed resting on two short pegs with the bulb just touching the tips of the grass, kept at about 2 cm long. The soil at Westbury-on-Trym is a clay-loam topsoil over a calcareous clay subsoil (Lower Lias). The bare plot was left undisturbed and kept free from weeds by using a total weed-killer. All thermometers were read and reset at 09 GMT in winter and at 08 GMT in summer. The surface thermometers were situated within 2 metres of each other, at a distance of 6 metres from the screen.

Analysis. The grass-minimum depression is forecast as routine at most stations and this analysis has therefore considered all minima in relation to the magnitude of the measured depression. Consequently the surface minima each night were expressed as follows:

- (a) Air-minimum minus grass-minimum temperature (G),
- (b) Concrete-minimum minus grass-minimum temperature (C) and
- (c) Bare-soil minimum minus grass-minimum temperature (S).

Grass-minimum depression (G). Craddock and Pritchard⁴ used data from 16 stations in their examination of this variable and showed that under favourable conditions a maximum value of 5 degC could be reached. Steele *et alii*⁸ present figures which suggest that the highest values for 10 stations in eastern England

reach 7 degC on very few occasions. Hogg,⁹ however, has shown that the maximum values for six places in south-west England ranged from 7 to 9 degC over a 10-year period, with one other station (Tavistock) recording a maximum depression of 11 degC.

The distribution of the grass-minimum depression at Westbury-on-Trym during the 2 years of this investigation is summarized in Table I, which also shows the frequency of the observations when the depression was at least 6.5 degC.

TABLE I—GRASS-MINIMUM DEPRESSION (*G*) AT WESTBURY-ON-TRYM, JANUARY 1972–DECEMBER 1973

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean (degC)	3.23	3.73	4.76	4.78	3.67	3.48	3.10	2.89	3.87	4.04	4.31	4.31	3.86*
Highest (degC)	7.8	8.1	8.8	7.1	6.9	7.5	6.5	6.7	6.3	7.3	7.8	7.3	8.8†
No. of obs.	43	40	43	38	41	43	43	44	38	45	44	36	498‡
No. of obs. ≥ 6.5 degC	5	7	14	9	2	3	1	1	0	2	9	3	56‡
Percentage of obs. ≥ 6.5 degC	12	17	33	24	5	7	2	2	0		20	8	11*
* Mean.	† Extreme.		‡ Total.										

These figures confirm that the maximum value of the grass-minimum depression in south-western England is greater than in eastern England. In all months except September, there was at least one night when the depression reached 6.5 degC, and in the important spring months, it is notable that the percentage of such nights was highest, reaching 33 per cent in March and 24 per cent in April.

Concrete-minimum temperature difference (C). The monthly distribution of the difference between the concrete and grass-minimum temperatures is given in Table II. To illustrate the occurrence of relatively large values of this variable, the frequency of nights when the magnitude was at least 2.5 degC is also shown.

TABLE II—CONCRETE-MINIMUM MINUS GRASS-MINIMUM TEMPERATURE DIFFERENCE (*C*) AT WESTBURY-ON-TRYM, JANUARY 1972–DECEMBER 1973

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Mean (degC)	1.14	1.46	2.03	2.47	2.09	2.04	1.96	1.71	2.30	2.16	1.96	1.69	1.92*
Highest (degC)	3.5	3.8	3.9	5.0	5.2	5.2	4.5	3.8	4.1	4.2	4.7	3.5	5.2†
No. of obs.													
≥ 2.5 degC	5	10	16	20	15	16	15	12	19	22	17	4	171‡
Percentage of obs. ≥ 2.5 degC	12	25	37	53	37	37	35	27	50	49	39	11	34*
* Mean.	† Extreme.		‡ Total.										

The frequency of the large values of (*C*) from November to March was lower than expected. There were 90 occasions of frost over concrete during this period and this confirmed the observation of Thornes¹⁰ who stated 'When the surface temperature falls to 0.0°C, the moisture both in and on the concrete begins to change state to ice; this takes place with the water at constant temperature around 0.0°C (depending on impurities, etc.) and any further fall of the surface temperature is delayed because of the release of latent heat as the water freezes'.

Again, there were fewer large values of S than expected during the winter months, and similar reasoning to that given for the concrete-minimum temperature applies. These results largely reflect those reported by Gloyne¹¹ who used a bare-soil minimum thermometer supported 0.5–1.0 cm above the soil. The seasonal analysis is given in Table V and the regression equations in Table VI.

TABLE V—RELATIONSHIP BETWEEN GRASS-MINIMUM DEPRESSION (G) AND BARE-SOIL MINIMUM MINUS GRASS-MINIMUM TEMPERATURE (S)

		Grass-minimum depression degC					
		<2.4	2.5–3.4	3.5–4.4	4.5–5.4	5.5–6.4	≥6.5
		Bare-soil minimum minus grass-minimum temperature					
Spring	Mean (degC)	0.64	1.34	1.96	2.66	3.43	3.51
(Mar.–May)	No. of obs.	27	17	11	19	23	25
	σ	0.46	0.55	0.58	0.57	0.55	0.67
Summer	Mean (degC)	0.78	1.49	1.66	2.81	3.26	4.62
(June–Aug.)	No. of obs.	54	22	12	26	11	5
	σ	0.53	0.71	0.86	0.57	0.63	0.72
Autumn	Mean (degC)	0.39	1.31	2.11	2.60	2.92	3.53
(Sept.–Nov.)	No. of obs.	28	17	19	23	29	11
	σ	0.63	0.53	0.66	0.80	0.52	1.04
Winter	Mean (degC)	0.36	1.15	1.74	2.49	2.96	4.71
(Dec.–Feb.)	No. of obs.	33	19	23	15	14	15
	σ	0.50	0.54	0.54	0.84	1.25	1.26
Year	Mean (degC)	0.58	1.34	1.87	2.66	3.13	3.94
	No. of obs.	142	75	65	83	77	56
	σ	0.56	0.62	0.66	0.69	0.75	1.08

σ = standard deviation of the observations.

Regression equations have been derived on a monthly and seasonal basis and these are given in Table VI together with their correlation coefficients. These enable estimates of the minimum temperature over concrete and over bare soil to be made directly from the grass-minimum depression.

Conclusions. Under favourable conditions, the grass-minimum depression at Westbury-on-Trym frequently exceeds 7 degC, and can reach 9 degC on a few nights in spring.

Seasonal and annual relationships have been established between the magnitude of the grass-minimum depression and the differences between (a) the concrete and grass minima and (b) the bare-soil and grass minima. These differences all show high correlation with the grass-minimum depression and it is suggested that they can be used to forecast the minimum temperature over each surface directly from the grass-minimum depression, which is now forecast as routine at most stations.

It is stressed, however, that these results have been derived at one place in south-west England, and that elsewhere they should be used with some caution. Further, it is suggested that thermometer bulbs just touching the surface might be giving values slightly less than those of the surface itself (perhaps by about 0.5 degC) so that freezing of the surface does not occur until after the reading of the thermometer has fallen a little below 0°C.

TABLE VI—MINIMUM TEMPERATURES OVER DIFFERENT SURFACES—REGRESSION EQUATIONS

	Concrete-minimum minus grass-minimum temperature difference	Correlation coefficients	Bare-soil minimum minus grass-minimum temperature difference	Correlation coefficients
	Regression equations <i>C</i>	<i>r</i>	Regression equations <i>S</i>	<i>r</i>
January*	0.35 <i>G</i>	0.92	0.67 <i>G</i> - 0.29	0.88
February	0.42 <i>G</i> - 0.11	0.83	0.64 <i>G</i> - 0.49	0.88
March	0.42 <i>G</i> + 0.03	0.86	0.53 <i>G</i> - 0.14	0.87
April*	0.48 <i>G</i> + 0.17	0.81	0.52 <i>G</i> - 0.09	0.92
May	0.58 <i>G</i> - 0.11	0.85	0.60 <i>G</i> - 0.17	0.94
June	0.55 <i>G</i> + 0.12	0.87	0.58 <i>G</i> + 0.08	0.91
July*	0.55 <i>G</i> + 0.25	0.88	0.53 <i>G</i> + 0.16	0.83
August	0.47 <i>G</i> + 0.34	0.83	0.49 <i>G</i> - 0.05	0.80
September	0.46 <i>G</i> + 0.54	0.86	0.51 <i>G</i> + 0.20	0.86
October*	0.49 <i>G</i> + 0.20	0.86	0.51 <i>G</i> - 0.04	0.86
November	0.44 <i>G</i> - 0.03	0.82	0.61 <i>G</i> - 0.61	0.88
December	0.37 <i>G</i> + 0.11	0.75	0.56 <i>G</i> - 0.57	0.78
Spring	0.47 <i>G</i> + 0.13	0.84	0.54 <i>G</i> - 0.08	0.90
Summer	0.53 <i>G</i> + 0.24	0.86	0.55 <i>G</i> + 0.01	0.85
Autumn	0.44 <i>G</i> + 0.29	0.82	0.53 <i>G</i> - 0.17	0.86
Winter	0.39 <i>G</i> - 0.03	0.85	0.62 <i>G</i> - 0.43	0.85
Year	0.45 <i>G</i> + 0.20	0.82	0.55 <i>G</i> - 0.14	0.86

C concrete-minimum minus grass-minimum temperature

S bare-soil minimum minus grass-minimum temperature

G grass-minimum depression

* The relationships in the months indicated are shown in Figures 1 and 2 overleaf.

REFERENCES

1. BOYDEN, C. J.; A method of predicting night minimum temperatures. *Q J R Met Soc, London*, **63**, 1937, pp. 383-392.
2. MCKENZIE, F.; A method of estimating night minimum temperatures. London, Meteorological Office, 1944. (Unpublished, copy available in Meteorological Office Library, Bracknell.)
3. SAUNDERS, W. E.; Night cooling under clear skies. *Q J R Met Soc, London*, **75**, 1949, pp. 154-160.
4. CRADDOCK, J. M. and PRITCHARD, D.; Forecasting the formation of radiation fog—a preliminary approach. London, Meteorological Office, 1951. (Unpublished, copy available in Meteorological Office Library, Bracknell.)
5. SAUNDERS, W. E.; Some further aspects of night cooling under clear skies. *Q J R Met Soc, London*, **78**, 1952, pp. 603-612.
6. PARREY, G. E.; Minimum road temperatures. *Met Mag, London*, **98**, 1969, pp. 286-290.
7. RITCHIE, W. G.; Night minimum temperatures at or near various surfaces. *Met Mag, London*, **98**, 1969, pp. 297-304.
8. STEELE, L. P., STROUD, P. A. J. and VIRGO, S. E.; An empirical approach to forecasting grass minimum temperatures and the probability of grass minima below 0°C in eastern England. *Met Mag, London*, **98**, 1969, pp. 340-348.
9. HOGG, W. H.; Frequency of ground frost in SW England on radiation nights. London, Meteorological Office, 1949. (Unpublished, copy available in Meteorological Office Library, Bracknell.)
10. THORNES, J. E.; An objective aid for estimating the night minimum temperature of a concrete road surface. *Met Mag, London*, **101**, 1972, pp. 13-25.
11. GLOYNE, R. W.; Radiation minimum temperature over a grass surface and over a bare-soil surface. *Met Mag, London*, **82**, 1953, pp. 263-267.

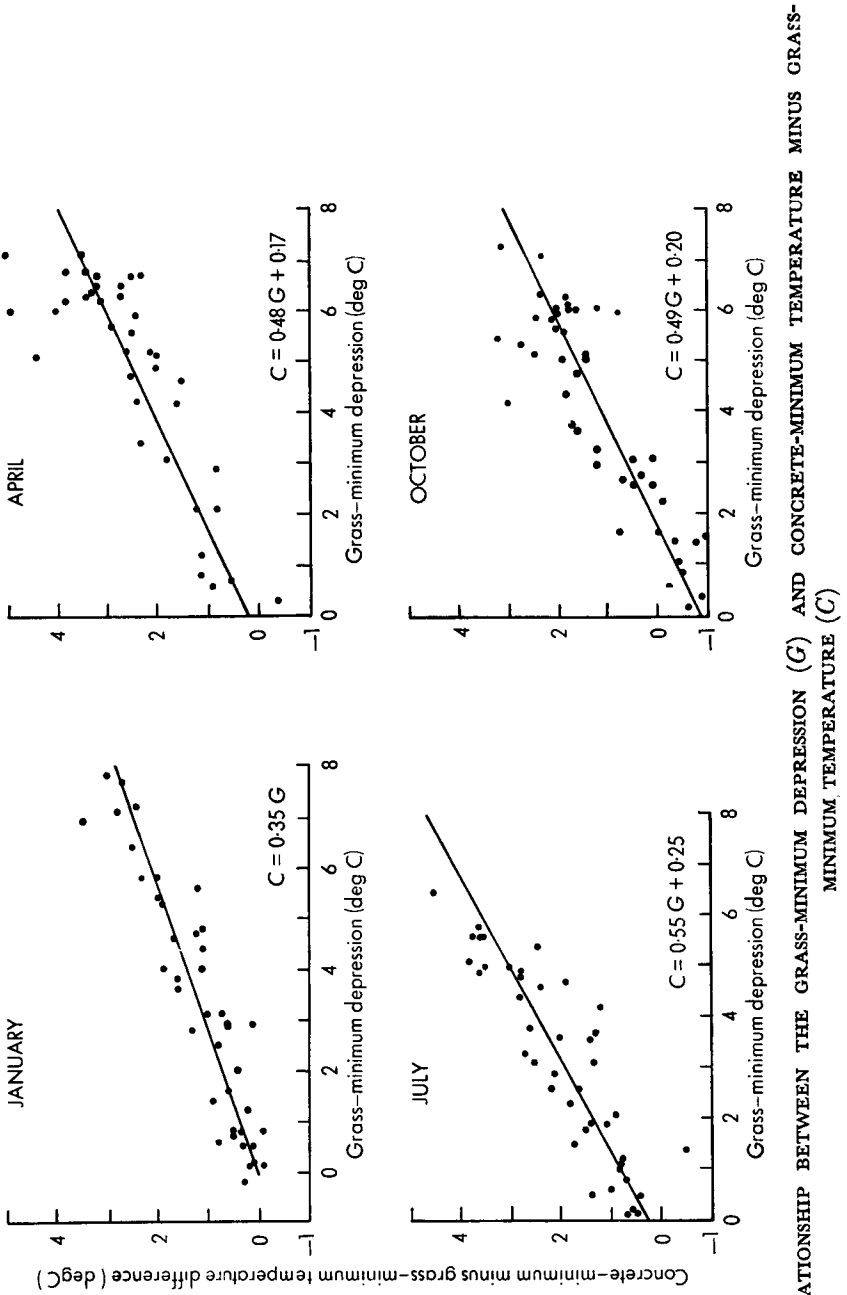


FIGURE 1—RELATIONSHIP BETWEEN THE GRASS-MINIMUM DEPRESSION (G) AND CONCRETE-MINIMUM TEMPERATURE MINUS GRASS-MINIMUM TEMPERATURE (C)

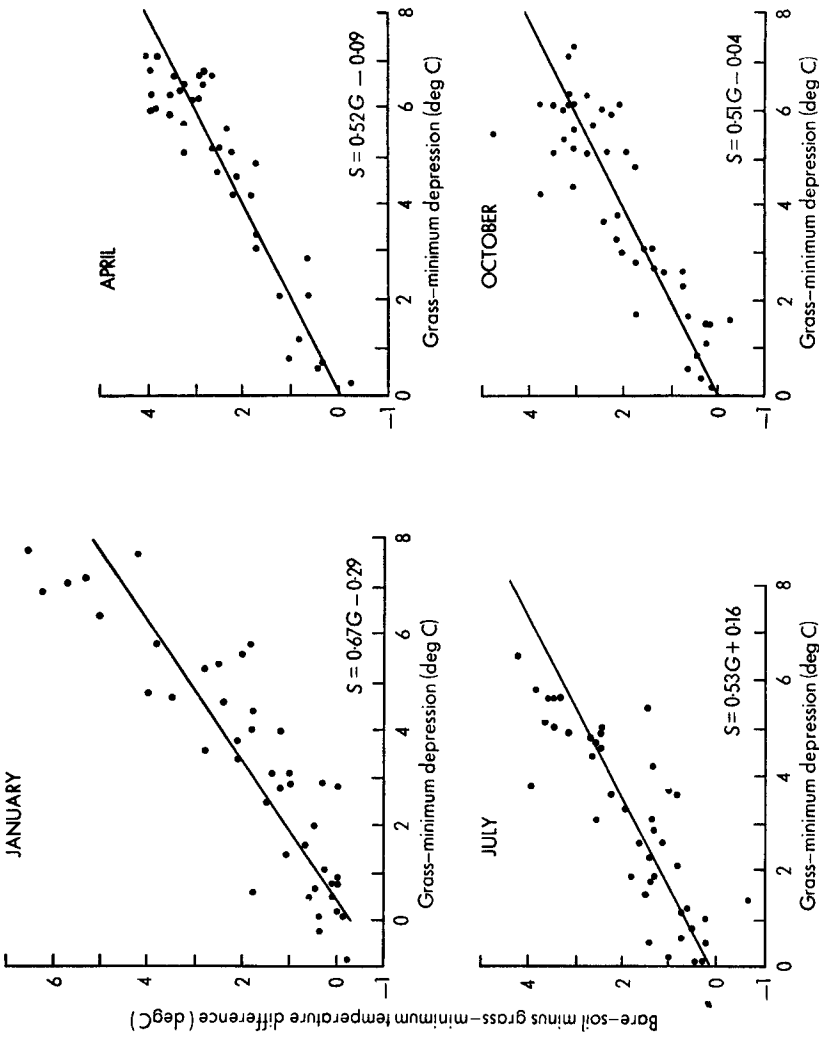


FIGURE 2—RELATIONSHIP BETWEEN THE GRASS-MINIMUM DEPRESSION (G) AND BARE-SOIL MINIMUM TEMPERATURE MINUS GRASS-MINIMUM TEMPERATURE (S)

REVIEWS

World climatology—an environmental approach, by J. G. Lockwood. 250 mm × 180 mm, pp. xiv + 330, *illus.*, Edward Arnold (Publishers) Ltd, 25 Hill Street, London, W1X 8LL, 1974. Price: £8.50.

The recent quickening of interest in Man's natural environment has come at a time when new methods of observation and analysis have brought great advances in knowledge of global climatology and deepened understanding of the processes by which climate is generated and which cause it to vary with time. The text here reviewed is of moderate length, lavishly illustrated by a large number of maps and diagrams, some of which explain the workings of climate, while many others contribute to a great variety of practical applications. It was time to write a new text, and this one may serve as a modern companion to Kendrew's well-known works. It provides an English-language text with many of the virtues of Dr Joachim Blüthgen's *Allgemeine Klimageographie* (published in Berlin by Walter de Gruyter & Co., 2nd edition 1966).

Lockwood's book is very much its author's child, admirable on the topics that have interested him and fairly comprehensive on fundamentals, but patchy when it comes to regional coverage. There is much on south Asia and on equatorial climates, particularly in the Malaysian-Indonesian sector, much less on east Africa and hardly anything on South America. Nevertheless, the short chapter (11 pages) on polar climates is good. Climatic change and the variability of conditions from year to year do not appear in the index at all (though there are a few items on year-to-year variations in the text). Mathematical expressions are used, where appropriate, to define concepts and relationships, but there are no mathematical derivations. The author's concern about definitions has led to the inclusion of a useful short glossary; a number of concepts, however, are only barely defined, not expounded in any way devised to help those readers to whom the field is new. Apart from this criticism, the text and especially the diagrams struck the reviewer as admirably clear. The author has the true geographer's facility for portraying processes in three dimensions. A particularly nice trio of diagrams (on page 196) makes clear why showers reach their maximum in the evening on the east coast of Malaya. The extreme clarity of the maps has, however, generally been attained at the cost of omitting the latitude and longitude net altogether.

Many of the pictures are outstanding choices, and they illustrate a wide range of environmental conditions from icing on ships in polar waters, and tornadoes and lightning flashes, to a good selection of satellite and aircraft photographs of cloud systems in various parts of the world.

The book has been written with the interests of agriculturists, botanists, civil engineers, geographers and meteorologists, and university students in these subjects, in mind. This has clearly guided the choice of matter for tables and diagrams, which include a variety of data on evapotranspiration, soil moisture, soil temperatures, water balance, streamline diagrams, albedo maps etc. The world map (page 42) of mean annual albedo, derived from satellite measurements, is interesting because it manifestly does not support the latest, often quoted, estimates of 30 per cent or less for the global average albedo. Other points of interest in the book include a rather good global survey of the incidence of tropical storms (though without explaining the absence of these storms in the

South Atlantic), an account of the occurrence of frosts in Java (from observations in the tea estates at the higher levels), and a likening of the change of wind with height in the free air to the corresponding Ekman spiral in the current movements in the upper layers of the ocean.

The author has written in a way that will stimulate many in their quest for deeper knowledge and understanding. As he states in the preface, 'most climatological text books concentrate on the mathematics and physics of the atmosphere and neglect the environment created by the atmosphere'. As the statement implies, they also generally neglect the seas which cover 70 per cent of the earth and the processes in the seas that affect the atmosphere. This book does not contain a lot about the ocean, but the subject is not neglected: the book does, for instance, present Tucker's revision of the usual ideas of distribution of precipitation over the ocean. Unfortunately the startling nature of Tucker's result is not stressed, nor the fact that it seems to have been largely disregarded in most estimates of the total global precipitation and its distribution.

This is a useful book, and a nice book, that will encourage pursuit of the subject, but it is not a fully comprehensive or encyclopaedic text such as the climatologies of Kendrew or the German texts from Hann to Blüthgen. It is a modern supplement to the older works, which no library covering applied climatology can afford to be without, and which those individuals who can afford it will find attractive and widely informative.

H. H. LAMB

The physics of mesospheric (noctilucent) clouds, edited by J. Ikaunieks. 245 mm × 170 mm, pp. viii + 156 (translated from the Russian by Israel Program for Scientific Translations, Jerusalem), John Wiley & Sons Ltd, Baffins Lane, Chichester, Sussex, 1974. Price: £7.50.

The book is another of the excellent translations from the Israel Program for Scientific Translations whose standard is kept at a high, though not always truly idiomatic, level. The original Russian text was published in Riga in 1970 and is an assembly of 22 of 30 papers originally presented at the 1968 Riga Conference on Mesospheric Clouds. All the papers at this conference are by authors from the U.S.S.R., which is perhaps natural because—until recent years—studies of noctilucent clouds have, in the main, been made in the U.S.S.R. Although the papers are now six years old, the development of the subject has not been as rapid as that in other areas of mesospheric studies and much of the research reported in the book has not been overtaken by events or become of only historical interest.

Many of the papers deal with the possible influence of solar activity upon the occurrence of noctilucent clouds, with the keynote sounded by a review of the Megrelishvili and Khvostikov concept of terrestrial accretion of hydrogen from the solar wind to give 'solar rain' in the mesosphere. The experimental data—mainly statistical analyses for a 10- or 11-year periodicity—retain their interest but the theoretical models are almost certainly open to criticism in the light of present ideas. The most convincing analysis is possibly that reported by Vasil'ev, who demonstrates a correlation between the rate of occurrence of noctilucent clouds and both the sunspot number and a four-year cycle in the difference between the monthly means in the January and the February tropospheric temperatures.

For researchers interested in the subject of airglow—the emission of light from the upper atmosphere—there is an important paper by Toroshelidze in which he reports an extensive series of twilight measurements of the hydroxyl emission at $1.08\text{-}\mu\text{m}$ wavelength. Vasil'ev and Fast present an interesting discussion of the optical effects seen in the atmosphere during the summer of 1908 after the fall of the Tunguska meteorite, particularly mentioning the curious 'bright nights' that were remarked at the time. Bronshten's review of the history of the discovery and early investigations of noctilucent clouds contains much that was new to this reviewer.

In summary, this book is like so many conference proceedings: many years have gone by since the papers were originally presented, there is no single thread of development through the book and the contributions differ considerably in level of treatment. However, given the particular character of noctilucent cloud studies, these proceedings survive well and can be recommended to be on a bookshelf available to any aeronomer or meteorologist.

M. GADSDEN

Climatology from satellites, by E. C. Barrett. 240 mm \times 155 mm, pp. xii + 418, illus., Methuen and Co. Ltd, 11 New Fetter Lane, London EC4P 4EE, 1974. Price: £7.90. (Also distributed in the U.S.A. by Harper and Row Publishers, Inc., Barnes and Noble Import Division, New York.)

Every meteorologist seems to have his own personal definition of the term 'climatology', so perhaps the scope of this book is not immediately clear from its title. However, at the outset, Dr Barrett defines the various subdivisions of the subject and identifies those which can be profitably pursued by making use of data from meteorological satellites. Because of the ease of access to the American literature, the author concentrates throughout on the U.S. systems, and, in an early chapter, summarizes the characteristics of the various satellites in operation since TIROS I was launched on 1 April 1960. The general problems associated with orbits, sensors and data acquisition, processing and presentation, are also briefly covered in this chapter.

The next two sections, of three chapters each, are devoted to 'Principles of weather satellite data analysis' and 'Satellite data analyses in global climatology'. This distinction is not altogether successful since in the first of these sections the principles obviously need to be illustrated with examples, which tend to overlap and duplicate the coverage given in the second section. Separate chapters are devoted to (radiative) energy, moisture (including cloud cover and rainfall) and circulation patterns.

The largest section in the book covers the use of satellite data in studies of regional climatology. The tropics (two chapters), the south Asian monsoon area, the baroclinic mid latitudes and the polar regions are all given detailed treatment, with greatest emphasis being laid on those aspects which have benefited most from the study of satellite data.

The final chapter, on the classification of climates, briefly covers the drawbacks of existing methods of classifying climate on global and regional scales (basically Köppen and modifications) and goes on to suggest an approach to classification more related to meteorological first principles. It is proposed that net radiation, relative vorticity and the precipitation/evaporation balance be

used as 'yes/no' or 'positive/negative' discriminators to define climatic regions, and with recent advances in data acquisition on a global scale, it is argued that this approach is now becoming feasible.

Throughout, this book is extremely readable, smoothly relating climatological concepts (both established and emerging) to the new forms of data now available. Satellite jargon is kept to an acceptable minimum, the bibliography is extensive and up to date and typographical errors are few. Diagrams are clear and the (black-and-white) photographs show many examples of how processed data may be presented.

All in all, this is a book to be recommended as a modern view of global climatology and also as a summary of the practical achievements of meteorological-satellite technology over the last decade.

J. S. HOPKINS

PUBLICATIONS RECEIVED

The following have been received from the Meteorological Institute of the University of Thessaloniki:

Climatologica 4: *The etesian winds: proof of the stability of the climate of Greece.*

By G. C. Livadas. 1974. (In Greek.)

Meteorologica 33: *Sequences of rain and drought in Thessaloniki (II).* By V. E. Angouridakis. 1973.

Meteorologica 34: *On a certain effect of mountain masses on aerial photography.* By E. N. Patmios and G. C. Livadas. 1973.

Meteorologica 35: *Wind in Thessaloniki—Greece.* By G. C. Livadas and Char. S. Sahsamanoglou. 1973.

Université de Thessaloniki. *Annuaire de l'Institut Météorologique et Climatologique*, 42. *Observations Météorologiques de Thessaloniki 1973*, publiées par le Prof. Dr. G. C. Livadas, Thessaloniki, 1974.

NOTES AND NEWS

The Atlantic Tropical Experiment of the Global Atmospheric Research Programme

The operational phase of the Atlantic Tropical Experiment of the Global Atmospheric Research Programme (GATE) has now been completed. Important contributions to this major international project were made by teams from the United Kingdom on two small chartered ships, H.M. Survey Ship *Hecla* and the C-130 aircraft of the Meteorological Research Flight. This aircraft logged 336 hours in 40 operational missions with almost no faults either in its own performance or in the instruments carried. Most of the flights were made at low level in order to measure fluxes of heat, water vapour and momentum, the aircraft being one of only three that were equipped to do this. The aircraft was one of the most versatile taking part in GATE and was used by the Airborne Mission Scientist as lead aircraft on 17 occasions. In Phase 3 it was struck by lightning which destroyed one of the wind vanes.

Climatological Atlas of the United Kingdom

The preparation by the Meteorological Office of a Climatological Atlas of the British Isles based largely on data covering the period 1901–30 was begun in 1938 but had to be suspended at the outbreak of the Second World War. Work was resumed in 1945 and the Atlas was eventually published by H.M. Stationery Office in 1952. This edition went out of print in 1966.

Work on a new atlas covering the United Kingdom for the period 1941–70 was started in 1972 and is well advanced. However, it has become apparent that this atlas cannot be marketed unless it is heavily subsidized. Reluctantly the Meteorological Office has had to take the decision not to subsidize and therefore not to publish it.

It is intended that separate sections each dealing with a particular element will be prepared and published in a cheaper form. A start has been made with barometric pressure and *Climatological Memorandum* No. 51A can now be obtained from the Meteorological Office, price £3.50. This Memorandum contains monthly and annual mean-sea-level pressure maps for 09 GMT for the United Kingdom for the period 1941–70, and some additional statistics. It is hoped to have further sections available soon: sunshine maps by the end of 1974, maps showing the number of days with snow falling and snow lying and of gales early in 1975, and a memorandum on temperature by mid 1975. Humidity maps will be available later. The prices of these publications have yet to be determined.

The display of climatological data in an atlas must of necessity be rather stereotyped and generalized and cannot meet all the requirements of many practical users. For them the Meteorological Office can usually undertake to process and present climatological data in a way which is suited to a client's particular needs, for a fee depending on the staff and computer time taken up.

New Joint Financing Agreement on North Atlantic Ocean Stations

A new Joint Financing Agreement on North Atlantic Ocean Stations (NAOS) has been concluded in Geneva by the Conference of Plenipotentiary Delegations convened at WMO Headquarters by Dr D. A. Davies, Secretary-General of WMO. The Conference, which was sponsored by WMO and the International Civil Aviation Organization, first met from 18 February to 1 March and then from 4 to 15 November 1974 under the chairmanship of Mr Raymond Schneider, Director of the Swiss Meteorological Institute and Permanent Representative of Switzerland with WMO.

The new Agreement will operate under the auspices of WMO, and will ensure the joint operation and financing of a network of four ocean stations in the North Atlantic primarily for meteorological purposes. This Agreement will in fact replace as from 1 July 1975 an existing Agreement concluded in 1948 under the auspices of the International Civil Aviation Organization which organized the NAOS network for the primary purpose of providing adequate air navigation facilities over the North Atlantic. In adopting the new Agreement the Conference recognized that the NAOS network is essential for weather forecasting in the northern hemisphere.

The four stations are located in the central and eastern parts of the North Atlantic and each of them will be permanently occupied by a vessel specially equipped and staffed to carry out surface and upper-air meteorological observations plus a number of secondary services including retransmission of weather reports, safety services to other ships and aircraft and oceanographic observations. The stations will be operated by the U.S.S.R. (Station C (52°45'N, 35°30'W)), the United Kingdom (Station L (57°N, 20°W)), the Netherlands, Norway and Sweden (Station M (66°N, 02°E)) and France (Station R (47°N, 17°W)). Two or three ocean-going vessels are required for the regular operation of each station. The unit of account will be the pound sterling and it is estimated that for the first financial period, i.e. 1 July 1975 to 31 December 1976, the average operating cost will be about £1 000 000 per station.

The financial basis of the Agreement is that, while the countries mentioned above will operate the network of NAOS stations, the other signatory countries will make financial contributions to the cost of the operations. The initial duration of the Agreement will be until 31 December 1981; it may thereafter be extended from year to year. A Board on which all participating countries will be represented has been established to supervise the operation of the Agreement, which will be administered by WMO.

The Secretary-General of WMO presided over the signing ceremony which took place at WMO Headquarters on 15 November 1974. The Agreement will remain open for signature until 31 May 1975.

WMO PRESS RELEASE

Retirement of Mr P. F. Illsley

Mr P. F. Illsley joined the Meteorological Office as a Technical Officer in 1937 after graduating from the University of Nottingham with a first-class honours degree in Physics. Following training at Croydon he was soon engaged in forecasting duties for aviation. During the first part of the Second World War he had many postings in this country which included short spells at several RAF Group Headquarters and Prestwick, and a rather longer one at Dunstable. Later he joined the Royal Air Force Volunteer Reserve (Meteorological Branch) and served in North Africa. On release from the RAFVR in January 1946 Mr Illsley again served for short spells at several RAF stations which were closing. He then served for two years at Gibraltar.

On his return to the United Kingdom in 1948 he was promoted to Principal Scientific Officer and served for a normal tour of duty as Senior Meteorological Officer, Plymouth. This was followed by eight years on the Senior Forecasters' Bench at the Central Forecasting Office, Dunstable from 1952 to 1960. Subsequently he served as Chief Meteorological Officer at Headquarters RAF Germany from 1961 to 1964 and at Headquarters Coastal Command from 1964 to 1972.

He was promoted to Senior Principal Scientific Officer and moved to Bracknell in 1972 in order to head the Climatological Services Branch in which he stayed until his retirement on 31 January 1975.

I have known him since the pre-war days at Croydon in April 1937. Throughout his career, which has been almost entirely concerned with meteorological services, Mr Illsley has displayed a very forthright approach to his work. Those of us who had occasion to discuss the current meteorological situation or forecast with him soon appreciated that forthright—sometimes somewhat blunt—expression of his views, which were usually based on a very keen perception and understanding of the situation and shrewd assessments of the likely developments. To telephone him at CFO for a discussion of the meteorological situation was always a refreshing and beneficial experience and usually—but not always—comforting. He brought the same refreshing direct approach to his work as Head of the Climatological Services Branch and has maintained it during his four years at Bracknell. With his retirement the Meteorological Office will miss his long and broad experience in practical meteorological matters.

Mr and Mrs Illsley are retiring to Church Stretton, Shropshire. Their many friends and colleagues in the Meteorological Office will, I am sure, wish them both a long and happy future.

N. BRADBURY

AWARD

Dr Raymond Hide, F.R.S.; Head of the Geophysical Fluid Dynamics Laboratory, Meteorological Office, Bracknell, has been awarded the Charles Chree Medal and Prize for 1975 by the Institute of Physics, in recognition of 'his contributions, both experimental and theoretical, to the hydrodynamics of rotating fluids and its application to the understanding of motions in the atmospheres and interiors of the major planets'.

OBITUARY

It is with regret that we have to record the death of Mr J. J. Trainor, Assistant Scientific Officer, on 14 November 1974 while in approved employment in Australia.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

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