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SIR GRAHAM SUTTON, C.B.E., F.R.S.

Sir Graham Sutton, C.B.E., F.R.S. died on 26 May 1977. Born in 1903 at Cwmcarn in Monmouthshire, Oliver Graham Sutton (he preferred to be known as Graham Sutton) received his early education at the local elementary school and at Pontywaun Grammar School. Thence he went to the University College of Wales at Aberystwyth and subsequently to Jesus College, Oxford where he completed his formal training as a mathematician. From 1926 to 1928 he held a lectureship in Pure Mathematics at Aberystwyth. Then he joined the Meteorological Office and within a short time was posted to the Chemical Defence station at Porton. It was there that he laid the foundations of the scientific work which was eventually to earn him an international reputation. The Meteorological Department at Porton was greatly concerned with atmospheric diffusion in the lower layers of the atmosphere, and Sutton applied his mathematical skill with considerable success to extending G. I. Taylor's theory of turbulent diffusion.

It was at Porton that Sutton first met N. K. Johnson (later Sir Nelson Johnson), the man he was eventually to succeed as Director of the Meteorological Office. Johnson had been at one time in charge of the Meteorological Department at Porton and had moved on to become Director of Experiments at the same station. Sutton eventually became Head of the Meteorological Department and later, in 1942, succeeded Johnson as Director of Experiments.

Temporarily Sutton left the world of meteorology to become the first Superintendent of Tank Armament Research in 1943, and later Chief Superintendent of Radio Research and Development in 1945. Following the cessation of hostilities, Sutton was appointed Bashforth Professor of Mathematical Physics at the Royal Military College of Science, Shrivenham in 1947. Here he remained until 1953, combining with his other duties those of Scientific Adviser to the Army Council in 1951 and Dean of the College in 1952–53.

In 1953 Sir Nelson Johnson retired from the post of Director of the Meteorological Office and Professor Sutton succeeded him. Eventually this second period in meteorology was to last almost as long as his earlier career at Porton. His very varied experience was to serve the Office well. Johnson had laid the foundations of the post-war Office but a very great deal remained to be done. Looking back, one can see Sutton's guiding hand in the interchange of men and ideas between the research and services sides of the Office, the development of meteorological services for the non-aviation customer, the unification of the three parts of the Office from London, Harrow and Dunstable, and the introduction of the first electronic computer. Internationally too he carved a name for himself as a member of the Executive Committee of the WMO from 1953 to 1965. This latter work he probably enjoyed more than he would freely admit: he was a logical thinker and a good advocate.

Some who worked with Graham Sutton found him a little unapproachable and difficult to get to know. Basically he was a rather shy man and protected himself with the armour of reserve. Behind this façade, however, there was a kindly and considerate man, a loyal colleague and—for those who worked closely with him—a rock of dependability who was never flustered. In discharging the wide duties of Director (later Director-General) of the Meteorological Office he fought hard in the interests of his staff—more so perhaps than was always generally realized since, given the circumstances of the time, he was not always able to achieve what he wanted. It is significant that he was President of the IPCS from 1957 to 1961. His human relationships were occasionally enlivened by an impish sense of humour. While in hospital recovering from an appendicitis operation he once told a nurse that the reason why the blankets always fell off the bed on the same side was the direction of rotation of the earth.

Sir Graham (he was knighted in 1955) retired from the Meteorological Office in 1965. He had intended his retirement to be complete but the world does not willingly relinquish the services of one who has achieved eminence both as a scientist and as an administrator. The Natural Environment Research Council (NERC) had been created that year and Sutton was persuaded to act as Chairman of this Council for one year. In the event he filled this post for three years and remained for another three years as a member with special responsibilities for hydrology and atmospheric sciences. There is no doubt that he found this work a very agreeable extension of his career as a scientist and administrator in the world of meteorology. Equally his wide experience and considerable abilities served the newly formed Council well in its earliest years.

Having relinquished the position of Chairman of NERC, Sir Graham was able to carry out his original intention when he retired from the Meteorological Office. In 1969 he left Berkshire and returned to his native Wales where he and Lady Sutton set up home in Swansea. He had been a member of the Council of the University College of Wales, Aberystwyth from 1958 to 1964, and in 1967 he was elected Vice-President of the College. I am indebted to the late Sir Ben Bowen Thomas, President of the College, for information about the last part of Sutton's career. The resumption of activities at Aberystwyth was a natural one. Not only had he received his university education there but so also had his two brothers and his sister. More important, it was there he met the lady who was to become his wife. As Vice-President of the College he showed great concern for students' welfare and was also able to draw on his experience gained in the Meteorological Office while acting as Chairman of the Buildings Committee. On matters of academic policy he showed the wisdom and foresight which had characterized his work in the Meteorological Office. He retired from the Vice-Presidency in 1976 on account of ill health.

During his career Sutton also found time to serve as Chairman of the Atmospheric Pollution Research Committee (1950–55), as a member of the Nature Conservancy (1956–59), and as Justice of the Peace. He wrote various scientific papers and books. These latter included *Micrometeorology* (1953), *Mathematics in action* (with D. S. Meyler, 1953) and *Compendium of mathematics and physics* (1957).

Inevitably many marks of appreciation fell to him during his lifetime. The following honours and awards indicate the esteem in which he was held: F.R.S. (1949), C.B.E. (1950), President of the Royal Meteorological Society (1953–55), Knight Bachelor (1955), President's Gold Medal, Society of Engineers (1957), Symons Gold Medal, Royal Meteorological Society (1959), International Meteorological Organization Prize (1968), Frank A. Chambers Award, Air Pollution Control Association (1968). He also became an Honorary Member of the American Meteorological Society, an Honorary Life Member of the New York Academy of Sciences, and he received honorary degrees from the universities of Leeds and of Wales.

In 1931 Graham Sutton married Doris, daughter of T. O. Morgan, and they had two sons. Lady Sutton, with her husband, graced many Meteorological Office functions. Our sympathies are with her and their sons.

A. C. BEST

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A HOMOGENEOUS RECORD OF MONTHLY RAINFALL TOTALS FOR NORWICH FOR THE YEARS 1836 TO 1976

By J. M. CRADDOCK
(Climatic Research Unit, School of Environmental Sciences, University of East Anglia)

SUMMARY

An account is given of the preparation of a series of monthly rainfall totals approximating to those which could have been recorded with a modern standard rain-gauge at the observing station in Heigham Cemetery, Norwich in the years 1836 to 1976.

1. INTRODUCTION

This series of monthly rainfall totals to represent Norwich is one of several now under preparation which are intended to facilitate comparisons between the climates of these and former times. It is published in part fulfilment of a contract with the Natural Environment Research Council for the production of long homogeneous rainfall records to represent different districts in Great Britain. The background is outlined in a paper by Craddock (1976) which shows, by reference to annual rainfall totals only, the availability of ancient rainfall records in different parts of England. For eleven districts, which include East Anglia, there are rainfall measurements taken within the district for each year before the present back to 1830, and for some districts the records extend back much earlier, till 1725 in fact. This paper seeks to increase the knowledge of past rainfall at Norwich by producing monthly as well as annual totals, and by concentrating on making reliable estimates for a representative key site, instead of surveying rainfall over the whole of England.

2. THE EVIDENCE

The first record of rainfall at Norwich was made by W. Arderon for the years 1750 to 1762, and published in the *Philosophical Transactions of the Royal*

Society. Then one unknown observer kept a record at Aylsham from 1787 to 1790, and another did so in Norwich from 1791 to 1799. After 1799, East Anglian rainfall records are missing, apart from one at Epping from 1820, and those by Orlando Whistlecraft at Thwaite, near Mendlesham (1830–81), until W. Brooke started observations in Upper Surrey Street, Norwich in 1836. He was followed by an observer at the Norwich Literary Institute in 1840, and every year afterwards there have been at least two rainfall observers active in Norwich. By the publication of a meteorological magazine in 1860, which still continues in essence in the annual volumes of *British Rainfall*, G. J. Symons gave a great impetus to the measurement of rainfall and the standardization of rain-gauges. During the 1870s the Revd. Canon Du Port actively encouraged the development of what became the Norfolk Rainfall Organization. This work was continued after Canon Du Port's death in 1898 by a Norwich Solicitor, Mr A. W. Preston, who in turn gave place to Col. H. C. Copeman in 1930 to perform a task which Mr T. W. Norgate performs today. Thus it is that in recent years there have been far more good rainfall records for stations in and around Norwich than could be considered in the present study, while for years before 1860 it is often hard to find reliable information of any kind. The rainfall stations considered in this paper are shown in Figure 1 in a form which shows which stations were operating in which years. Most have been used in comparisons made to confirm the reliability of the records used in the final result, and to suggest the best correction factors where necessary. The need for comparison and correction will be clear from the following paragraph.

3. The development of rain-gauging

In 1723, Dr James Jurin, the Secretary to the Royal Society, issued to his members an 'invitation to make weather observations according to a common plan'. He recommended a rain-gauge which had some surprisingly modern features, but all he said about its exposure was that it should be placed where no obstacle could prevent rain from any direction from reaching the gauge. Now the modern understanding of the position, as outlined, for example, by Painter (1975), is that the amount caught by a rain-gauge is considerably affected by eddies in the wind passing over the gauge, eddies which may be generated by surrounding objects, or by the gauge itself, in the general sense that the stronger the wind, and the smaller the droplets, the greater the deficiency. A rain-gauge exposed without protection on the flat ground around Norwich, or on an isolated roof, is sure to collect less than a similar gauge in a situation such as a large garden or forest clearing, where the wind speed is reduced by obstacles which are not near enough to intercept any of the rain. William Arderon made his rainfall observations in 1750 when, as reported by Parson Woodforde in 1780, the city gates were still shut at night, and during the nineteenth century most Norwich rainfall observers were gentlemen of means, living in houses lying within or near to the present ring road, and hence well within the present-day built-up areas. It is unlikely that any observers from 1850 onwards would start with gauges at ground level which were over-exposed, and which hence would benefit by protection. The trend must usually be in the other direction, that over the years the growth of trees and the erection of buildings tends to intercept the rain and to reduce the catch from what may originally have been a satisfactorily exposed gauge. Whereas many early rainfall records depended on home-made gauges of primitive design, the efforts of G. J. Symons and others led to the increasing adoption of well-made gauges from firms such as Negretti and Zambra which conformed to known standards and had a long working life. Hence the problems of reducing rainfall records for different years to a common standard tend to reduce to the following:

(a) the average annual rainfall at the site of the gauge may be different from that at the chosen key site;

(b) the gauge may be exposed under non-standard conditions: it may be sheltered by surrounding buildings or trees, or exposed to violent winds; in either case it is likely to catch less rain than it should; and

(c) the quality of the recording, though satisfactory to start with, may deteriorate with time, nearly always in the sense that the actual catch becomes progressively less than the true value.

The method described goes far towards overcoming all these problems, of which the last is by far the hardest.

4. The method of reduction

Given rainfall records made at two sites during a number of years, the ratios of corresponding annual totals are expressed as percentages, and plotted against the year number; the points are then joined to make the graph easier to read. If three or more records exist for the same period, then one record is chosen as standard, the annual totals being used as denominator in comparisons with all the others. Comparisons among the other records are also made on occasion, but it is rarely necessary to examine all possible comparisons. An example of such comparisons is shown in Figure 2, and they are considered in detail, after this discussion of principles.

Now the ratio of the total rainfall amounts caught at two sites in the same year must have an expected value, which is approximately the ratio of the climatic values at these sites. If the two sites are both in Norwich, where the climatic average rainfall is near 26 inches, the expected value of the ratio must be near unity, but even if the sites are widely separated, the ratio in individual years must fluctuate at random about some definite value. If the fluctuations are not at random about the ratio of the climatic values but tend to be always positive or negative, or to change with time, then either one of the climatic values has been wrongly estimated, or one or both of the rain-gauges has been wrongly installed, or the quality of one or both of the records is changing with time. These possibilities can be seen far more easily by looking at graphs plotted in the style of Figure 2 than they can from the table of figures on which the graphs are based, and this is a very sensitive method of finding features in rainfall records which call for explanation. If the graph suggests that the ratio of the annual catches at two sites has remained stable over several years, there is some justification for estimating the ratio as accurately as possible, from the data during the period of agreement, and using this ratio to extend one record by means of estimates based on the other. When, however, the ratio seems to be changing with time, the reason for the change must be investigated and allowance made for it.

5. The Norwich key site in recent years

The first reason for choosing the rain-gauge site in Heigham Cemetery to represent Norwich is that it lies near the city in an open space which is likely to remain unchanged for many years to come. A second reason is that a good

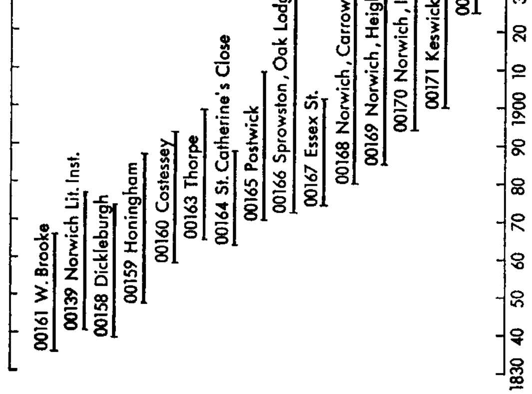

FIGURE 1—NORWICH RECORDS USED IN THIS STUDY
(The numbers 00161 etc. are unique identification numbers.)

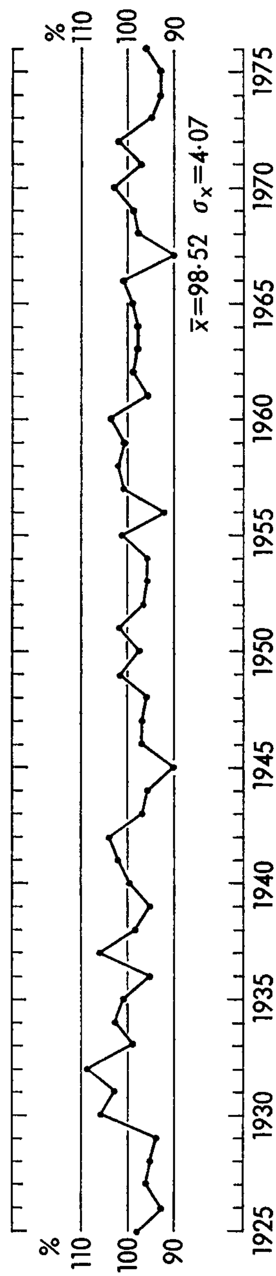

FIGURE 2—ANNUAL RAINFALL TOTALS AT OLD LAKENHAM AS PERCENTAGES OF THOSE AT HEIGHAM

record has been kept at or near the same site since the year 1885. Figure 2 makes it possible to judge the validity of this record for the years since 1926. It gives the ratio of the annual catches at Old Lakenham, tabulated by Mr A. E. Attoe, the observer there, over the corresponding totals for Heigham, extracted from the Meteorological Office archives. The average ratio for the 57 years is 98·52 per cent, with a standard deviation of 4·07 per cent. The graph suggests a maximum soon after 1930 followed by a decrease until about 1945, but because of random year-to-year variations this may be no more than a statistical accident. It is interesting to relate this to the remarks made about the Heigham observing site by the official inspectors. In 1926 the note read, 'Gauge in planting-out garden adjoining lodge of cemetery. Exposure excellent.' In 1958 it read,' Oversheltered in all directions. No available sites', and in 1970, 'Site sheltered by glass-houses etc. and overshadowed by beech trees to E'. Since the Heigham totals are in the denominator in the ratios in Figure 2, any reduction in the relative catch there should produce an upward trend in the graph, which clearly has not occurred. The probability that two long-period records should change their character in the same year and in the same direction and to the same extent seems small, and the natural inference from Figure 2 is that both Heigham and Old Lakenham are reliable records, at least during the years 1930 to 1972, and that if any uncertainty attaches to the years outside this period it is Old Lakenham which is suspect.

6. Comparisons between records

The standard deviation of the ratios in Figure 2, 4·07 per cent, is typical of those found in several such comparisons, where the stations concerned are a mile or two apart. The mean value, 98·52 per cent, is only a little below 100 per cent, but the difference is probably significant because in Figure 2 there are only 18 points above the 100 per cent line, against 33 points below. Figure 3 shows a similar comparison between the annual totals at Heigham for the years 1895 to 1950 with those of four other stations. The nearest is that kept by J. Willis at Southwell Lodge in Ipswich Road from 1894 till 1940 which shows a feature noticeable in many early records: that the annual catches decline steeply for a few years before the record ends. The most likely explanation is that the observer is prevented by age or infirmity from remedying defects which in earlier years he would have corrected. If the years 1938–40 are excluded, the standard deviation of the ratio (Ipswich Road/Heigham) $\times$ 100 is 3·52 per cent, one of the lowest found in this experiment. There is no suggestion of any general change in the Heigham standard between 1895 and 1950, although the Heigham totals in 1933 and 1934 seem anomalously low. It should be noted, when comparing records from closely grouped stations, that an unexpectedly high value at one station may be due to an isolated thunderstorm, whereas a correspondingly low total, which (if genuine) would imply anticyclonic conditions which extend over a wide area, can hardly occur at one station without affecting the others. Furthermore, the existence of the Norwich Rainfall Organization and the publicity it receives is likely to result in any local anomaly being observed and remarked upon. If, for example, a garden shed erected next to the rain-gauge leads to a reduced annual catch, the observer may draw the inference and rectify the situation, perhaps before any query is received from the Meteorological Office. The addition of 5 per cent to the annual catches at Heigham for 1933 and 1934 would bring points for these years in Figure 3 into

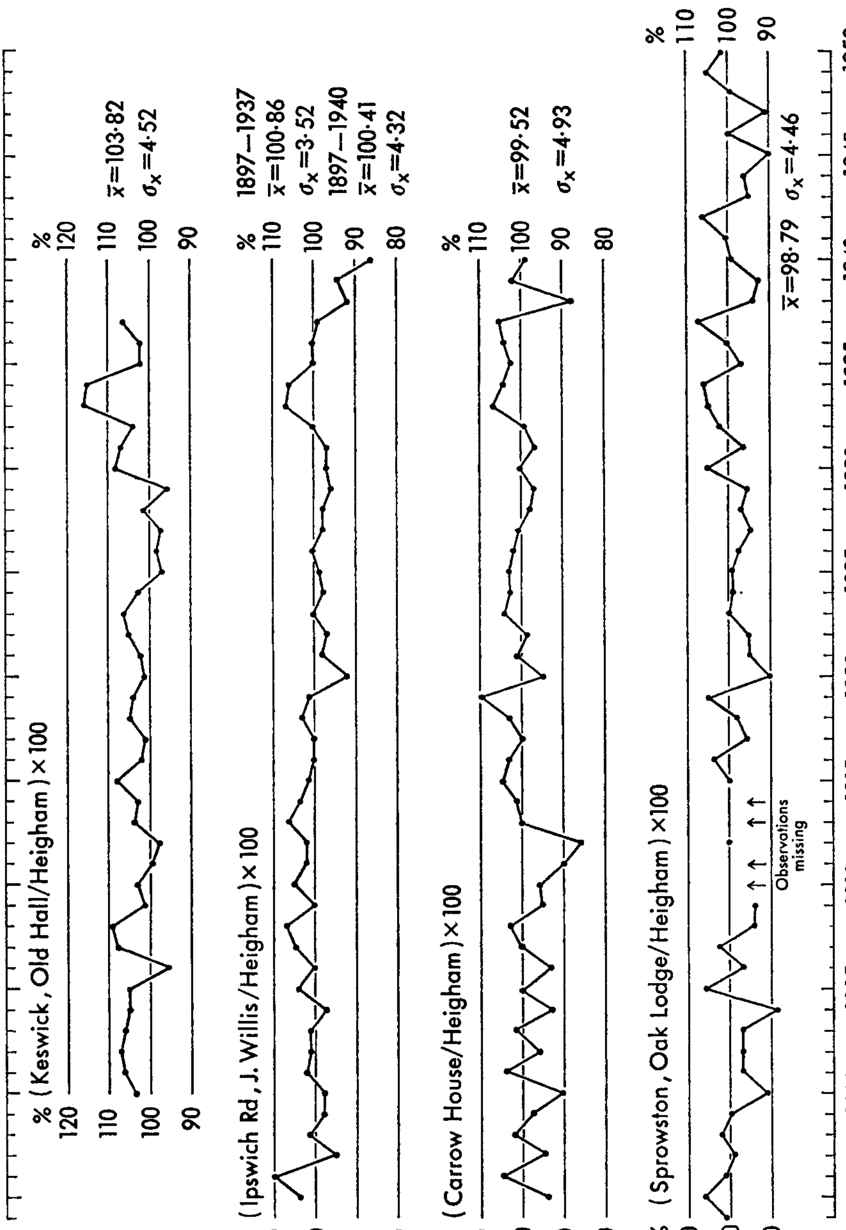

FIGURE 3—RECORDS FOR 1895–1950 COMPARED WITH HEIGHAM

line. The dip in the graphs in 1920 show that the Heigham total was relatively high in that year, but comparison of the 1920 monthly totals at Heigham with those at Carrow House shows that the excess total was nearly all due to excess rain in July, August and September. This rain was probably convective in origin, and no adjustment seems called for.

With the adjustment to 1933 and 1934 the Heigham figures are accepted back to 1885, and the problem then arises of finding the best early records to adjust to the Heigham site. Figure 4 shows a comparison for the period from 1873 onwards of four stations' records with that at Sprowston, Oak Lodge, which in later years was consistent with Heigham. None of these shows rapid deterioration with time, and any of them could be used to extend Heigham back to 1878.

The most satisfactory record for years before 1877 seems to be that made at the Norwich Literary Institute (NLI) from 1841 to 1877. This rain-gauge was on the roof, 30 feet above the ground; while it caught consistently less than a gauge at ground level, the elevation seems to have ensured that the exposure did not change materially during the 37 years. Comparisons show that the catch in 1865 was very deficient while the observation for 1841 is doubtful. With these exceptions, the main problem is to estimate the correction factor to bring the NLI observations into line with the Heigham record. The even earlier record made in Surrey Street by W. Brooke from 1836 to 1866 seems to have undergone

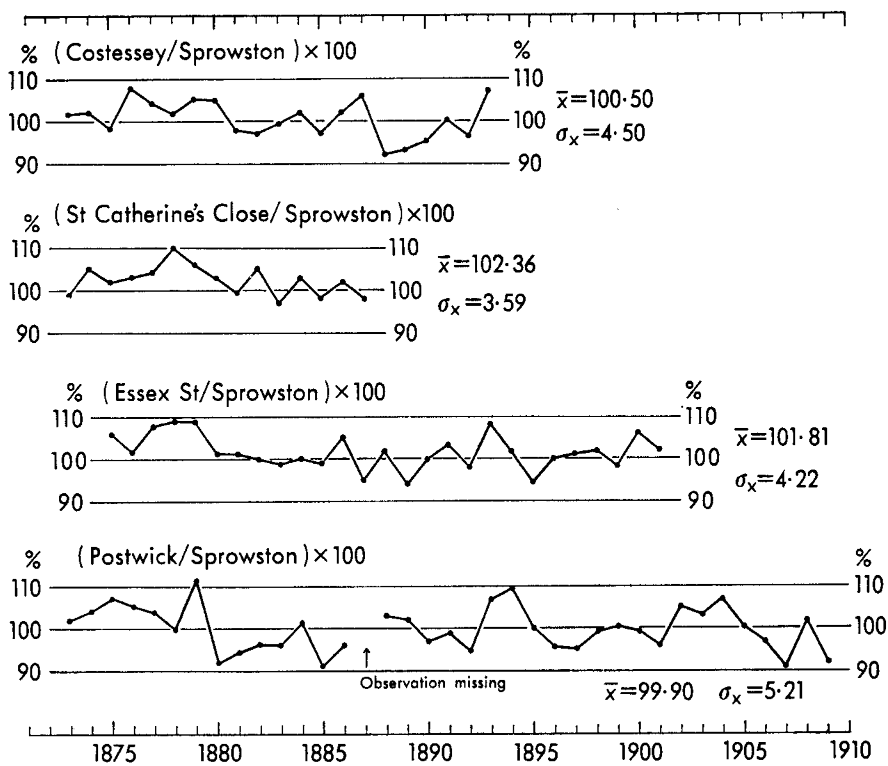

FIGURE 4—RECORDS FOR 1873–1902 COMPARED WITH SPROWSTON, OAK LODGE

a change in exposure in 1850.* Only the earlier part, for which there is no alternative, is used. The conversion factor to bring any record in Figure 4 into line with Heigham is the product of the mean ratio given with that of Sprowston to Heigham (0·9852), so that the factor for the record by F. Dix in Essex Street is 1·00303, not significantly different from unity. For H. Culley's record at Costessey the factor is 0·9901.

In Figure 5, covering 1858 to 1893, with H. Culley's Costessey record as base, the ratio back to the Heigham standard (and excluding the 1865 value) is $0{\cdot}9901 \times 0{\cdot}9152 = 0{\cdot}9061$. The comparison between Costessey and Lady Bayning's record at Honingham shows no long-term trend and, although the stations are 7 miles apart, the standard deviation, 5·90 per cent, is comparable with other records of the same period. Finally, Figure 6 shows a comparison between Mr Brooke's record in Surrey Street and that at the Norwich Literary Institute, first on the basis of Brooke's totals as given, and secondly on the basis that all Brooke's totals before 1851 are increased by a factor of 1·1555. The first

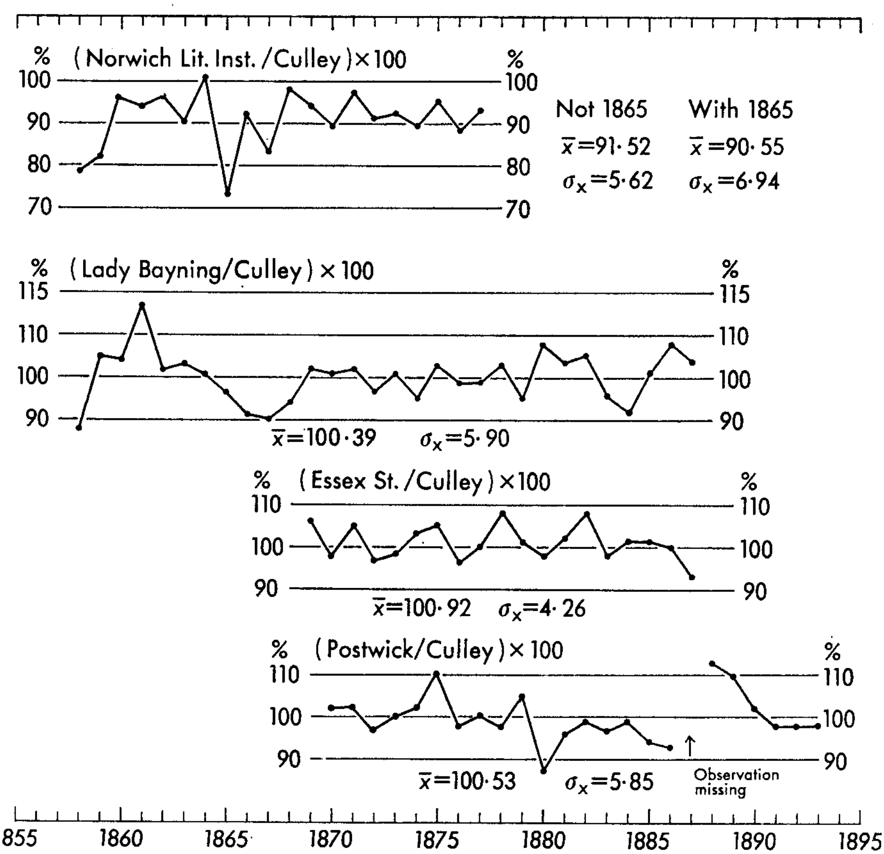

FIGURE 5—RECORDS FOR 1858–83 COMPARED WITH COSTESSEY (H. CULLEY)

* He may have changed from a roof gauge to a gauge at ground level. The observations up to 1850 are multiplied by 1·1555 to give the record referred to as 'Brooke 2' in Figure 6.

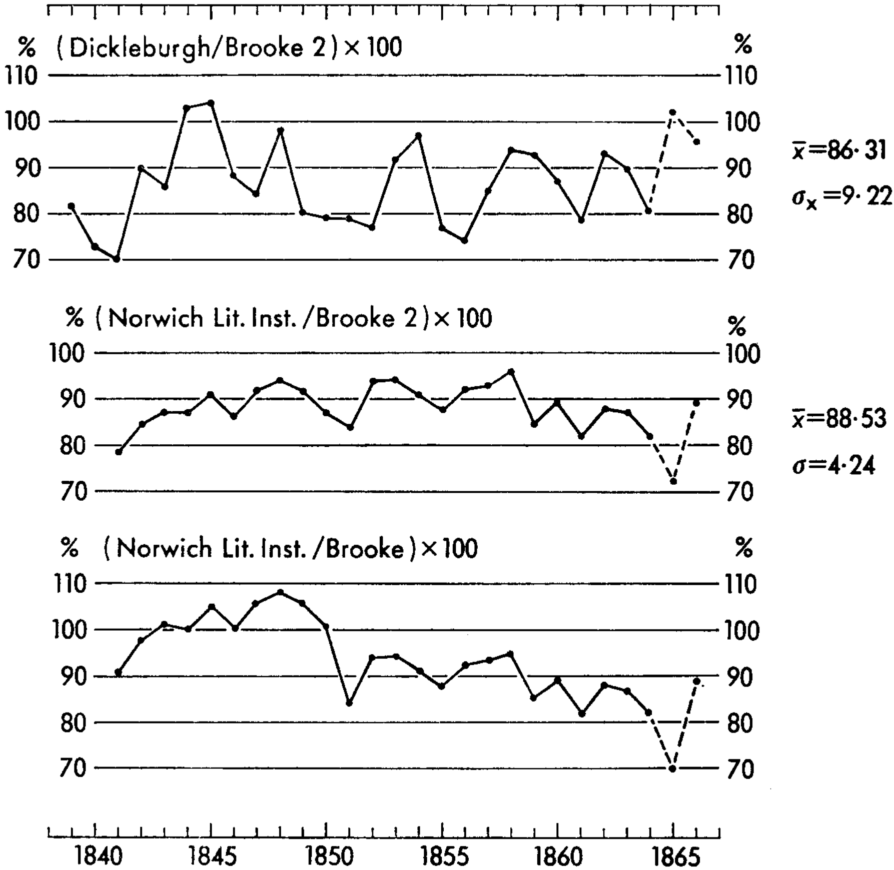

FIGURE 6—RECORDS FOR 1839–66 COMPARED WITH NORWICH, SURREY STREET (W. BROOKE)

comparison suggests a change in the ratio after 1850, which, on this evidence alone, could be either an increase in the relative catch by Brooke's gauge or a decrease in that at the Institute. However, a second comparison (not shown) between Brooke's original record and that of F. Dix at Dickleburgh, 17 miles away, suggests the first explanation,* and the final graph which compares the modified Brooke record with Dickleburgh suggests that, although there are important variations, there is no overall trend. The record kept by H. Culley covering the years 1858–93 seems to be very consistent, with a mean catch very close to that expected at the Heigham site. It does not show the defect in 1865 which occurs in the record at the Literary Institute, and the official records show that although Culley used a home-made gauge in 1858 he replaced it by a model by Negretti and Zambra in 1859. For these reasons the Costessey record is preferred from 1858 onwards, so that the final homogeneous record is made up as follows:

* The entries in *British Rainfall* show that W. Brooke had two rain-gauges after 1850, one near the ground and the other at roof level, and the inference is that his recorded figures relate to the roof gauge up to 1850 and the ground gauge from then on.

1836–1841	W. Brooke × 1·1290
1842–1858	Norwich Literary Institute × 1·1036
1859–1884	H. Culley × 1·0100
1885–1976	(except 1933 and 1934) Heigham Cemetery
1933 and 1934	Heigham Cemetery × 1·050.

The complete record is given in Table I, in inches.

7. Conclusion

The homogenization is probably accurate to within one per cent for years back to 1859, with rather more uncertainty about the conversion of the totals from the Norwich Literary Institute back to 1842. For the years 1836 to 1841, based on totals given by Mr W. Brooke, the average is probably about right, but there are unexplained variations between years which require more attention and may be very hard to elucidate. The same applies with even more force to the isolated records before 1836 back to 1750 which are not considered here. The present homogenization must be looked on as the best which can be offered at the moment, with the promise that something better may be produced later for years before 1842.

Acknowledgements

Acknowledgement is due to the Hydrometeorological Branch of the Meteorological Office for copies of most of the records used, taken from the official archives, and to Mr A. E. Attoe of Norwich for copies of records in his personal collection.

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Table I—Homogeneous monthly rainfall totals for Heigham Cemetery, Norwich, 1836–1974

	J	F	M	A	M	J	Jy	A	S	O	N	D	Total
1836	2·03	2·11	3·99	1·98	0·90	3·75	2·03	0·77	4·18	4·20	3·95	2·99	32·88
1837	3·61	2·56	1·07	1·90	1·47	1·98	3·05	2·82	1·73	2·54	2·60	2·82	28·15
1838	2·62	1·52	1·26	1·84	0·53	3·44	1·16	2·94	2·85	2·20	2·31	1·69	24·36
1839	1·75	1·47	2·37	1·02	1·30	3·27	4·01	3·07	2·99	2·20	2·99	2·82	29·26
1840	2·54	1·10	0·81	0·14	3·36	1·91	2·42	1·16	3·38	2·71	3·16	2·71	25·40
1841	3·42	1·99	1·64	1·74	1·87	2·29	5·95	4·29	4·22	7·81	3·49	3·90	42·61
1842	1·16	1·05	2·53	1·68	1·21	1·53	4·09	1·41	4·25	3·07	3·38	0·63	25·99
1843	1·99	2·81	1·11	2·21	4·25	2·30	1·94	4·78	2·16	4·24	3·89	0·26	31·94
1844	2·46	1·32	2·17	0·26	0·54	0·99	2·44	2·67	1·49	4·41	3·12	0·57	22·44
1845	2·21	0·72	0·17	1·80	4·24	1·08	2·01	4·24	1·11	2·37	1·36	3·24	24·55
1846	2·74	0·76	1·30	3·19	1·27	1·55	1·53	2·41	1·45	3·90	1·81	2·27	24·18
1847	1·27	1·07	1·19	1·79	2·89	3·06	0·55	1·67	1·81	2·28	1·93	2·70	22·21
1848	1·19	2·62	3·07	2·92	0·71	4·45	2·46	3·60	2·83	6·19	2·11	2·10	34·25
1849	1·71	0·62	2·04	2·89	5·45	1·30	2·37	1·69	2·09	3·60	2·13	4·41	30·30
1850	1·88	1·23	0·74	1·95	3·37	0·63	6·68	1·78	1·93	2·46	2·84	2·30	27·79
1851	2·39	0·81	3·30	2·94	1·35	1·75	4·04	2·60	1·06	3·13	3·79	0·57	27·73
1852	3·44	2·79	0·71	0·38	1·53	3·07	0·87	3·97	5·71	3·94	5·55	1·96	33·92
1853	2·17	3·07	1·29	3·02	0·67	2·42	5·37	3·45	1·70	3·53	1·45	1·49	29·63
1854	1·98	1·08	0·53	0·55	5·54	0·57	0·82	4·29	0·74	2·55	2·75	3·43	24·83
1855	1·18	1·91	1·40	0·29	1·42	3·03	3·87	1·62	0·92	3·59	2·98	1·96	24·17
1856	2·35	1·26	0·41	1·18	3·72	1·67	3·10	2·53	3·56	2·26	3·01	2·04	27·09
1857	4·19	0·22	0·68	2·43	0·98	1·94	2·14	2·66	5·44	3·10	1·61	0·38	25·77
1858	0·41	0·41	1·19	1·45	2·53	1·20	3·61	2·44	0·93	2·87	1·84	2·03	20·91
1859	0·99	1·36	1·35	3·45	0·94	1·53	2·68	2·40	2·90	2·51	2·02	3·15	25·28
1860	2·49	2·21	2·45	1·24	3·17	4·96	1·93	3·04	3·05	1·93	3·15	2·38	32·00

TABLE I—*continued*

	J	F	M	A	M	J	Jy	A	S	O	N	D	Total
1861	1·15	2·42	2·13	1·05	0·88	1·39	3·45	0·25	2·58	0·52	4·68	1·36	21·86
1862	1·11	0·40	4·20	0·96	2·74	1·88	1·04	2·25	1·80	2·54	1·52	2·03	22·47
1863	2·39	0·45	0·96	0·99	0·74	2·97	0·75	2·00	1·59	2·29	1·96	1·10	18·19
1864	0·49	1·28	1·91	0·09	2·31	1·01	1·13	0·86	1·82	0·84	2·08	0·80	14·62
1865	2·07	2·91	2·60	0·42	1·24	1·23	3·63	3·11	0·03	6·08	2·07	1·18	26·57
1866	2·68	4·19	1·14	1·56	1·86	2·93	2·05	1·23	2·46	1·02	3·37	2·65	27·14
1867	3·94	1·24	1·54	2·29	2·90	0·95	3·06	1·85	2·71	2·53	1·06	3·02	27·09
1868	2·14	1·50	2·08	1·92	0·80	0·71	0·56	2·85	2·29	2·64	2·26	4·52	24·27
1869	1·70	2·40	3·13	1·27	2·84	1·71	0·59	1·68	3·10	2·93	2·65	4·52	28·52
1870	1·22	0·81	1·56	0·89	0·62	1·13	1·93	2·20	1·63	3·89	1·44	4·19	21·51
1871	0·74	1·90	0·97	3·15	1·04	3·53	2·82	0·63	3·95	1·67	2·58	1·29	24·27
1872	2·07	0·94	4·00	2·28	2·10	3·16	3·32	3·71	2·84	3·18	4·21	3·78	35·59
1873	2·01	1·92	2·04	1·35	1·90	1·69	2·00	2·05	3·05	2·31	1·29	0·67	22·28
1874	1·08	1·09	0·86	1·05	1·96	2·08	1·12	1·36	3·22	1·67	3·19	2·47	21·15
1875	2·25	1·30	0·57	0·70	1·50	1·59	5·13	0·70	2·44	3·60	5·86	2·41	28·05
1876	1·85	2·91	2·86	3·26	1·13	1·78	3·41	2·00	5·19	1·26	2·56	3·48	31·69
1877	2·77	2·68	2·37	2·67	1·83	1·99	2·88	3·60	2·93	2·18	2·31	2·30	30·51
1878	2·09	1·17	1·15	0·99	3·63	1·61	0·53	5·11	2·34	2·36	7·73	2·10	30·81
1879	1·06	2·96	0·74	2·41	2·58	3·92	4·67	5·12	3·46	1·38	2·26	0·70	31·26
1880	0·11	1·74	0·73	1·90	0·76	3·61	4·67	2·77	2·26	5·10	1·98	2·34	27·97
1881	1·57	3·48	1·39	1·03	0·65	1·68	2·15	3·68	2·59	2·86	2·20	3·04	26·32
1882	1·75	1·45	1·27	3·22	1·62	2·91	2·77	1·75	2·40	5·89	3·72	3·81	32·56
1883	1·90	2·76	1·97	1·73	1·06	2·76	2·69	0·71	3·39	3·63	3·73	2·83	29·16
1884	1·38	0·51	1·32	2·01	0·87	0·52	2·19	1·47	2·72	3·05	2·33	2·47	20·84
1885	2·33	2·37	1·31	1·31	2·99	0·95	1·02	0·60	4·59	6·64	2·92	1·36	28·39
1886	2·67	0·23	1·35	1·47	2·54	0·52	3·98	1·82	1·75	2·94	2·61	3·84	25·72
1887	1·75	0·62	1·91	1·19	2·17	0·41	1·19	2·27	2·56	2·81	2·11	1·35	20·34
1888	1·36	2·00	2·53	1·60	0·95	1·00	3·95	2·20	1·84	2·13	2·67	1·14	23·37
1889	0·86	1·57	1·03	2·03	3·37	1·11	3·56	2·50	3·20	2·73	1·79	1·35	25·10
1890	2·57	0·74	2·74	0·97	1·61	2·82	3·33	1·87	0·98	1·87	3·59	0·56	23·65
1891	1·84	0·02	1·74	0·99	3·45	0·87	5·19	3·05	0·98	3·81	1·63	2·98	26·55
1892	0·92	2·05	1·15	1·82	1·71	3·41	2·69	2·26	2·03	7·82	1·30	1·25	28·41
1893	2·23	2·42	0·41	0·07	0·96	1·47	4·54	2·11	1·37	1·51	4·32	1·78	23·19
1894	1·70	1·16	0·93	2·25	2·63	2·42	3·70	2·33	1·85	2·59	3·05	3·13	27·74
1895	3·63	0·53	1·91	1·17	0·87	0·58	3·67	4·65	0·45	3·84	2·05	1·82	25·17
1896	1·02	0·43	3·45	1·17	0·66	2·32	1·09	1·76	3·56	3·15	1·62	3·25	23·48
1897	2·15	2·20	2·14	1·69	0·91	2·38	0·93	2·15	3·42	0·85	1·53	1·51	21·86
1898	0·93	1·14	2·10	1·07	2·99	3·23	1·50	1·50	0·17	2·15	2·56	2·14	21·48
1899	1·89	1·33	1·55	2·70	1·57	0·94	2·23	0·57	3·17	2·70	2·61	1·73	22·99
1900	3·06	3·23	1·05	2·03	1·77	3·13	2·01	4·65	0·56	2·25	2·08	2·87	28·69
1901	0·67	1·56	2·13	2·31	0·88	1·52	1·18	1·18	0·98	2·04	2·24	3·80	20·49
1902	1·30	0·69	1·05	1·29	4·18	2·28	2·22	3·24	1·15	1·47	1·49	1·31	21·67
1903	1·60	0·36	1·70	2·51	1·75	2·74	5·06	3·12	3·04	4·65	1·71	1·07	29·31
1904	1·40	2·83	1·79	0·75	1·69	0·67	2·98	3·07	2·09	1·42	1·64	2·09	22·42
1905	0·98	1·54	1·84	2·08	1·21	3·41	0·70	2·40	2·28	3·61	1·92	0·89	22·86
1906	3·73	2·64	1·79	0·66	2·88	2·09	1·05	2·10	1·12	2·99	4·37	2·79	28·21
1907	1·25	1·46	1·20	3·53	2·53	2·40	1·57	1·08	0·43	3·11	2·52	2·45	23·53
1908	0·85	1·99	2·17	2·57	1·60	1·23	3·38	2·31	2·23	1·23	1·44	1·42	22·42
1909	0·78	0·61	3·02	1·33	1·24	2·93	3·02	1,83	1·59	4·01	1·29	4·92	26·57
1910	2·74	2·02	0·82	2·36	3·61	1·68	3·77	1·14	1·40	1·59	4·05	4·16	29·34
1911	2·09	1·75	2·77	1·40	1·37	3·03	0·70	0·74	2·13	2·57	3·16	3·78	25·49
1912	2·64	1·42	2·25	0·40	0·92	2·19	3·74	11·36	2·65	1·77	3·04	2·44	34·82
1913	2·92	0·76	2·08	2·33	1·13	0·70	2·45	1·53	2·62	3·36	2·26	0·80	22·94
1914	2·06	1·60	3·46	0·74	0·94	1·58	2·81	0·82	1·12	2·37	2·91	6·36	26·77
1915	3·00	3·30	2·00	0·70	2·18	0·95	3·68	2·52	1·46	2·01	2·82	3·99	28·61
1916	1·71	4·54	3·58	1·75	2·41	3·08	1·03	2·87	1·73	2·53	2·81	3·02	31·06
1917	2·07	1·18	3·09	2·10	0·69	1·63	2·30	4·64	2·30	3·42	2·01	1·42	26·85
1918	2·58	1·09	0·73	3·17	0·71	1·11	3·34	1·54	4·40	2·49	2·05	3·80	27·01
1919	2·66	3·22	1·85	1·68	0·68	1·29	2·53	1·82	0·73	3·38	2·96	4·61	27·41
1920	2·25	0·69	1·16	3·37	1·63	1·93	3·28	2·00	2·47	0·75	0·79	3·05	23·37
1921	2·02	0·37	1·09	1·64	1·11	0·55	0·55	1·48	1·29	1·51	2·00	1·89	15·50
1922	5·33	2·66	2·15	2·43	0·56	1·45	7·51	1·46	2·75	1·46	1·91	2·50	32·17
1923	1·67	3·47	1·49	0·97	1·32	0·80	2·97	2·36	1·73	3·49	3·19	3·00	26·46
1924	2·23	1·92	0·70	1·89	3·75	1·53	2·30	2·49	5·06	4·57	1·38	2·76	30·58
1925	1·06	1·91	1·73	2·29	2·15	0·55	1·80	2·40	3·12	1·49	3·68	2·63	24·81
1926	2·64	1·93	0·38	2·74	1·49	2·54	1·60	2·42	0·95	2·75	3·09	1·34	23·87
1927	2·20	2·10	2·12	1·57	0·71	4·89	2·37	3·47	6·62	2·71	5·02	2·30	36·08
1928	3·51	1·50	1·50	1·36	1·87	2·34	2·02	1·67	1·15	2·68	2·83	3·29	25·72
1929	1·90	0·75	0·05	1·21	1·04	0·94	4·06	1·27	0·65	3·15	3·48	5·03	23·53
1930	1·85	0·95	1·35	2·11	3·01	1·01	3·98	2·46	5·25	0·91	3·70	1·86	28·44
1931	2·34	2·27	0·60	3·39	3·37	2·31	3·34	3·22	2·27	1·04	1·79	1·76	27·70
1932	0·79	0·77	1·92	3·12	3·65	0·48	3·39	1·88	2·52	4·17	1·43	0·65	24·77
1933	0·78	2·22	2·00	1·32	1·77	2·04	1·35	0·53	2·32	2·75	1·98	0·57	19·63
1934	1·44	0·89	1·20	2·35	2·33	2·16	1·17	1·69	1·64	1·80	1·75	3·75	22·17
1935	2·94	1·85	0·56	2·28	1·41	2·85	1·03	1·08	3·25	2·79	3·67	1·73	25·44
1936	2·63	2·39	0·40	1·44	0·64	3·94	3·92	1·70	2·41	2·08	2·82	1·46	25·83
1937	3·70	2·54	2·77	2·23	3·16	1·08	1·52	1·02	1·70	1·55	1·90	3·10	26·37
1938	2·21	1·22	0·35	0·52	1·89	1·00	3·17	1·06	2·59	2·90	2·15	3·61	22·67
1939	5·65	0·88	2·15	3·13	0·72	2·11	1·20	2·92	1·88	6·68	4·24	2·51	34·07
1940	1·81	1·42	2·89	1·48	0·80	0·31	3·89	1·32	1·00	2·17	6·01	2·19	25·29

TABLE I—*continued*

	J	F	M	A	M	J	Jy	A	S	O	N	D	Total
1941	2·26	2·36	2·92	0·78	1·91	0·64	1·18	3·96	0·42	3·44	1·92	1·23	23·02
1942	3·32	1·16	1·81	0·72	2·24	1·22	3·34	0·83	1·56	3·67	2·68	2·08	24·63
1943	3·80	0·62	0·80	0·93	1·98	1·44	1·41	1·52	2·31	1·61	2·81	1·27	20·50
1944	2·15	1·59	0·78	1·88	1·09	1·71	1·73	1·10	3·51	3·60	4·36	1·60	25·10
1945	2·49	1·76	1·92	2·59	2·15	1·79	0·88	3·95	2·42	3·05	1·08	2·54	26·62
1946	1·58	3·76	0·89	0·56	1·53	2·84	5·80	3·70	2·55	1·06	3·52	2·99	30·78
1947	1·89	2·51	4·56	2·01	0·51	1·34	1·53	0·04	0·83	0·41	1·23	1·98	18·84
1948	3·70	1·06	0·67	0·88	2·69	2·16	1·98	3·29	1·59	1·60	0·99	1·19	21·80
1949	1·01	1·00	1·41	1·81	1·52	0·97	2·33	1·69	1·15	3·16	2·43	1·77	20·25
1950	1·31	3·31	0·36	1·80	1·71	2·46	4·89	2·56	3·37	1·01	4·15	2·20	29·13
1951	3·05	3·12	3·56	3·44	1·72	0·97	2·22	3·13	2·09	0·76	3·53	1·29	28·88
1952	2·86	1·07	2·61	1·62	1·36	1·39	2·04	2·13	2·68	2·51	4·18	2·60	27·05
1953	1·46	1·60	0·59	2·22	1·25	2·18	2·70	2·67	1·78	2·26	1·37	1·03	21·11
1954	1·61	2·21	2·42	0·55	2·06	2·22	2·71	5·29	1·77	2·17	4·51	1·84	29·36
1955	1·85	2·21	1·87	0·43	2·05	2·58	0·28	0·88	1·94	4·66	0·84	1·82	21·41
1956	3·10	2·11	0·84	0·93	0·80	2·33	2·85	5·99	1·43	2·27	1·43	1·98	26·06
1957	1·82	2·34	2·02	0·21	1·19	2·23	2·58	2·33	3·51	1·44	2·20	2·50	24·37
1958	2·43	3·71	1·36	1·06	3·28	2·57	2·83	2·43	1·92	1·89	1·21	2·66	27·35
1959	3·20	0·18	1·35	1·59	0·38	1·13	1·60	1·34	0·05	1·74	2·43	3·01	18·00
1960	3·94	1·77	0·99	1·19	0·36	1·20	3·43	3·44	3·56	4·35	2·99	3·80	31·02
1961	3·56	1·37	0·50	1·79	1·22	1·22	2·46	2·68	3·31	4·48	2·56	2·98	28·13
1962	2·23	1·41	1·40	1·57	1·78	0·37	2·54	2·55	2·53	1·16	2·28	1·98	21·80
1963	1·06	0·72	2·31	2·00	2·07	1·63	1·63	4·11	1·58	1·58	2·68	1·11	22·48
1964	0·51	0·94	3·10	2·84	1·15	3·63	1·12	1·50	0·66	2·42	1·65	2·64	22·16
1965	2·14	1·27	2·34	2·44	2·28	1·93	3·93	2·49	3·68	0·80	2·90	4·88	31·08
1966	1·39	3·10	0·92	2·07	1·13	2·64	2·97	2·77	1·03	2·96	4·36	2·79	28·13
1967	1·34	2·12	0·78	2·32	3·44	0·70	1·28	1·60	2·37	3·90	2·42	1·95	24·22
1968	2·18	1·69	1·04	1·23	1·92	2·95	4·17	4·09	6·55	1·98	2·41	2·63	32·84
1969	2·10	2·95	2·27	2·24	3·76	1·40	3·47	3·35	0·30	0·44	3·47	2·68	28·43
1970	1·70	2·32	1·91	2·54	0·94	0·61	1·74	1·82	1·10	1·85	5·67	2·59	24·79
1971	3·05	0·81	1·74	0·89	0·81	2·10	1·96	2·99	0·86	2·21	4·59	1·35	23·36
1972	2·81	1·28	0·99	1·82	2·41	1·41	2·95	1·28	0·96	0·37	2·97	1·41	20·66
1973	0·74	1·12	0·47	2·83	2·70	0·88	3·37	1·16	3·87	1·96	1·07	1·80	21·97
1974	1·70	2·30	1·05	0·25	0·64	1·64	2·44	3·12	2·62	5·19	4·18	1·70	26·83

551.521.11:551.524.2(425 + 426)

THE SPATIAL VARIABILITY OF DAILY TEMPERATURES AND SUNSHINE OVER UNIFORM TERRAIN

By J. S. HOPKINS
(Meteorological Office, Edinburgh)

SUMMARY

Daily maximum and minimum temperatures and daily sunshine durations have been analysed at a network of stations over an 8000 km² area of uniform terrain in eastern England. Inter-station differences and correlations have been used to calculate standard errors of interpolation between stations of given separations. Some conclusions are offered concerning the required inter-station spacings in the UK climatological network.

INTRODUCTION

The problem of determining the optimum number of observation points to document the meteorology of an area of land surface adequately has long occupied both the synoptician and the climatologist. The former is concerned that observations should be sufficiently close in time and space to enable the position and development of significant weather features to be adequately defined for forecasting purposes. (What is 'significant' in this context obviously depends on the space and time scales under consideration, and what is 'adequate' must be decided by comparison of the attainable standard error of the combined analysis and forecasting process with the standard error acceptable to the user of the forecast.) The climatologist is concerned that observations should be available from all sub-areas which are considered to have recognizably different climates and that the effects of topography on the various climatic elements should be quantifiable to allow adequate estimates to be made at points with no data. (Here, what is 'adequate' must be decided by consideration of the interpolation accuracy required by the user of the information, bearing in mind the standard errors of the observations themselves.)

It is perhaps self-evident that an increase in the network density would result in improved accuracy of interpolation between stations, and so any discussion on 'optimum' densities should be accompanied by a consideration of the increased costs necessary to operate a denser network and the economic benefits likely to accrue from the denser data. In practice, of course, it is almost impossible to quantify these economic benefits, either in the synoptic or climatological context. The planning of observational networks, therefore, has tended to be a rather pragmatic process, governed by subjective considerations of what extra data appear necessary to 'fill a gap' in the existing network, and by the availability or lack of suitable observers and sites at the desired locations. The current development of accurate and reliable automatic weather reporting and recording instruments implies that station selection in the future should not depend so much upon these non-meteorological constraints, and instruments may be sited so as to provide the maximum benefit purely in terms of the meteorological information derived. Thus a more quantitative understanding is required of the spatial variability of the principal land surface meteorological elements, so that a more rational policy of observational network design may be pursued. We need to know the accuracy with which interpolation within the existing network can be achieved for the various elements and, as a corollary, the network spacings necessary to achieve stated levels of interpolation accuracy over various types of terrain.

The 650 or so stations in the UK climatological network are sited at an average density of about one per 400 km^2, but owing to the considerable dependence on voluntary observers, the network is very much weighted towards the more populous low-altitude areas, with a lower density in upland regions. Owing to the greater spatial variability of climate in topographically complex areas, this situation is thus the very reverse of what is required to achieve the estimation of climate between stations with reasonably uniform accuracy over the whole country. This paper describes the preliminary analysis of the spatial variability of three climatological elements—daily extreme temperatures and sunshine duration—over an 8000 km^2 area of uniform topography where variabilities can be expected to be smaller than elsewhere in the UK; the results will thus define the upper limit to station separations required to achieve an acceptable level of interpolation accuracy.

Previous network design studies

A short general discussion on the basic problems of network design can be found in Alaka (1970). Although primarily concerned with upper-air networks, his paper presents some ideas useful in the consideration of surface networks, and emphasizes the interdependence of station separation, observational accuracy and attainable (or required) accuracy of interpolation.

The planning of surface climatological networks by statistical analysis of available observations has been pioneered by Czelnai and co-workers (Czelnai *et alii*, 1963) and by Gandin, particularly in the latter's WMO *Technical Note* (1970). The essence of the Gandin approach was the use of two alternative measures of similarity between simultaneous values recorded at existing stations. They were the correlation coefficient (R) and the adjusted mean-square difference (S); these are defined by:

Correlation between N values of x at stations i,j:

$$R_{i,j} = \frac{\sum^{N}(x_i-\bar{x}_i)(x_j-\bar{x}_j)}{[\sum^{N}(x_i-\bar{x}_i)^2 . \sum^{N}(x_j-\bar{x}_j)^2]^{\frac{1}{2}}},$$

and adjusted mean square difference between N values at stations i, j:

$$S_{i,j} = \frac{1}{N}\sum^{N}[(x_i-\bar{x}_i)-(x_j-\bar{x}_j)]^2.$$

The variation of these parameters with station separation (L) enables the correlation and (so-called) structure functions, $R(L)$ and $S(L)$, to be defined; these could then be inserted into expressions derived by Gandin to give estimates of root-mean-square (r.m.s.) errors of interpolation for any required station separation. Separate expressions were presented to enable errors of interpolation to be calculated at the mid point of a line joining two stations, or at the mid points between three or four stations sited on a triangular or square grid respectively. Both linear and optimum interpolation* were considered, the S-function being used to derive errors in the former case, and the R-function in the latter case. For example, the expression for linear (E_{lin}) and optimum (E_{opt}) r.m.s. errors of interpolation at the mid point between two stations of separation L were:

$$E_{lin}^2 = S\left(\frac{L}{2}\right) - \frac{1}{4}S(L) + \frac{1}{2}\sigma_F^2$$

and

$$E_{opt}^2 = \sigma^2\left[1 - \frac{2\,R^2(L/2)}{1 + R(L) + (\sigma_F/\sigma)^2}\right],$$

where σ^2 is the variance, and σ_F is the standard error of observation of the element concerned at a typical point in the network.

In practice, however, if the variance of the element is reasonably uniform over the area considered, it can be shown that:

$$S\,(L) \approx 2\sigma^2\,[1-R(L)],$$

and, if also R and S are *linear* functions of L, then a simple relationship can be derived between E_{opt} and E_{lin}, i.e.

$$E_{opt}^2 \approx [1-R(0)]^2 + R(0).E_{lin}^2.$$

If $0{\cdot}9 < R(0) < 1{\cdot}0$, E_{lin} is very close to E_{opt}, and, since linear interpolation is much easier to carry out routinely, it is acceptable to use linear rather than

* In 'linear interpolation' in two dimensions the value to be interpolated at any point is derived by fitting a first-order surface (i.e. a plane) to the surrounding observations, the coefficients of the horizontal co-ordinates being determined by a least-squares error analysis over all the data points used.

In 'optimum interpolation' a formula is used that is a linear combination of the actual values at the surrounding data points, the coefficients or weights being derived from statistical theory by minimizing the mean-square error of interpolation over all occasions in the sample.

optimum interpolation when the above conditions regarding $R(0)$, σ^2 and linearity of $S(L)$ and $R(L)$ are satisfied.

Gandin's published examples of network analysis have dealt mainly with monthly mean data at stations typically hundreds of kilometres apart, but other workers, notably Czelnai (loc. cit.) and Hutchinson (1973) have analysed spatial variability of temperatures on the daily time scale in Hungary and Zambia respectively, albeit still on space scales which are large compared with typical inter-station distances available in the United Kingdom. It thus remains to be demonstrated that *R*- and *S*-functions for the principal meteorological elements behave coherently over uniform terrain for station separations below 100 km. The difficult problem of interpretation of these functions in areas of complex topography also requires attention.

In a slightly different approach to the question of network analysis, Sneyers (1973) assumed *ab initio* that the correlation function was linear for the Belgian climatological network, and that it could be defined simply by considering the correlation between data from two stations of known separation. This assumed function was then used to calculate the error of interpolation for a 'typical' station separation, which was shown to be acceptably small when compared with the generally recognized error of observation of the element concerned. (Monthly mean daily maximum temperatures, monthly rainfall amounts and monthly maximum wind speeds were investigated.)

DATA

The Gandin approach to the estimation of errors of interpolation has been used in this investigation and, as explained above, it seemed logical to select for initial attention data from an area of minimum topographic variation. Accordingly, the largest area in the United Kingdom possessing uniform terrain and reasonably uniform climate was chosen. Figure 1 shows the area concerned—East Anglia—stretching from Stamford and Bedford in the west to around Norwich in the east. Twenty-two climatological stations within this area (see Table I) were found to have daily data of acceptable quality over a period of at least 4 years within the period 1959–74. Nine of these stations had records covering the full 16 years. All stations observed daily maximum and minimum temperatures (where the day is conventionally taken to be the 24 hours ending at 09 GMT), and 17 stations also measured daily durations of bright sunshine, using a Campbell–Stokes recorder.

TABLE I—CLIMATOLOGICAL STATIONS USED IN SPATIAL VARIABILITY ANALYSIS OF DAILY TEMPERATURES AND SUNSHINE DURATIONS

Station number		Alt. (m)	Station number		Alt. (m)
3007	Terrington St Clement	3	3115	Broom's Barn	75
3024	Marham	23	3127	Honington	50
3031	Santon Downham	24	3234	Boxworth	44
3037	West Raynham	76	3245	Mepal	−2
3055	East Dereham	53	3248	March	2
3063	Morley St Botolph	48	3253	Cambridge Botanic Gdn	12
3071	Scole	27	3254	Cambridge NIAB	26
3075	Sprowston	28	3357	Monks' Wood	40
3078	Coltishall	17	3374	Wyton	40
3084	Burlingham	27	3456	Cardington	29
3107	Mildenhall	5	4396	Wittering	64

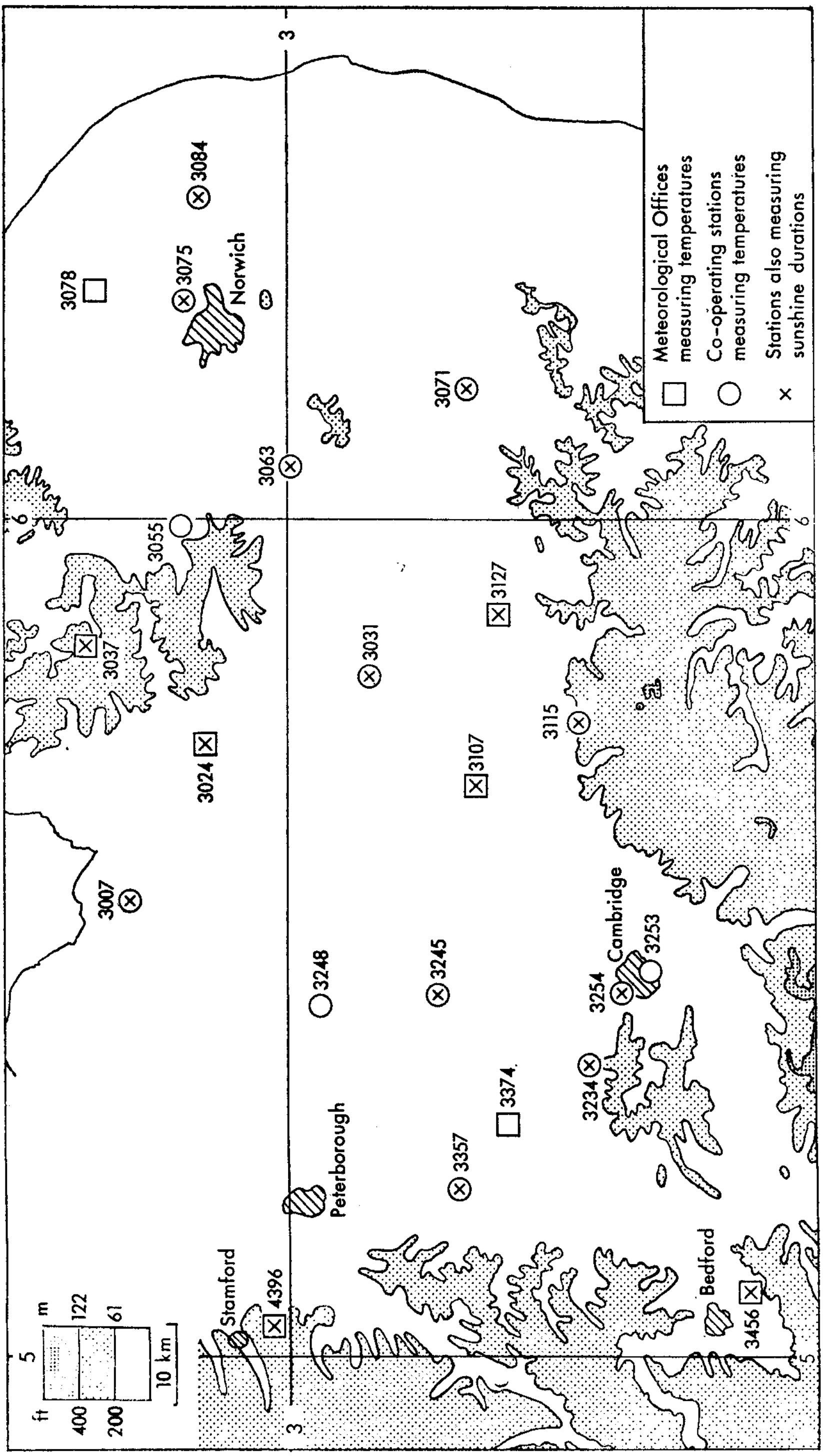

FIGURE 1—CLIMATOLOGICAL STATIONS USED IN STUDY OF SPATIAL VARIABILITY

ANALYSIS OF TEMPERATURES

January and February were taken to represent winter conditions, and July and August summer conditions. Since daily values of temperature are serially correlated, the use of N consecutive days' values would not yield N independent samples of spatial variability. Although there is considerable variation from year to year, typical autocorrelation coefficients for daily temperatures fall from about 0·65 for a lag of 1 day to about 0·2 for a lag of 3 days. (Coefficients are smaller in summer than in winter, and those for minimum temperatures smaller than those for maximum.) It was considered adequate to use values at 3-day intervals from all available stations to ensure that samples for spatial variability analysis were reasonably independent, both synoptically and statistically.

Using these values, for each station pair the correlation coefficient (R) and adjusted mean-square difference (S) were computed over the period of record common to both stations. If at least 50 pairs of values were available, then R and S were plotted as a function of station separation. Twenty-two stations would give a theoretical maximum number of 231 plotted points, but in practice this number was reduced to about 150 because some station pairs were recording simultaneously for a period too short to achieve the '50 pair' criterion.

Figures 2(a) and (b) show the R and S plots for winter minimum temperatures. It can be seen that the R plot displays a well-defined upper boundary, which can be taken as indicating the maximum correlation obtainable between stations of a given separation possessing very similar local exposure characteristics and attaining the highest possible standards of observational accuracy. These stations might be considered to constitute a 'best possible' network in East Anglia. Extrapolated to zero distance, this upper boundary gives $R(0) = 0{\cdot}99$. The lower boundary of the R plot is not so sharply defined. Figure 2(b) shows that the majority of the plotted S values lie within well-defined upper and lower linear boundaries, the latter defining the behaviour of the 'best possible' network. Those not lying between these boundaries were found to arise from comparisons of one single station with all others. That station was Santon Downham, whose frost hollow characteristics have been discussed by Oliver (1966). The correlation coefficients between data from Santon Downham and from all other stations have been plotted with a distinguishing symbol in Figure 2(a), and it can be seen that, although lying towards the lower edge of the R values, they do not stand out as clearly from the rest of the population of points as do the corresponding S values in Figure 2(b).

The same analysis for summer daily minimum temperatures gave rise to very similar R and S plots with Santon Downham appearing anomalously, particularly on the latter. Analysis of summer and winter maximum temperatures in the same fashion showed no such anomalous behaviour, all points lying within well-defined upper and lower linear boundaries for the S plots and below an upper boundary for the R plots.

The linear relationships with distance, defined by the upper R boundary and the lower S boundary, were used in the Gandin formulae to obtain r.m.s. errors of interpolation between stations 100 km apart; the relationship between R and distance to estimate errors arising from optimum interpolation, and the relationship between S and distance to estimate errors from linear interpolation. Table II confirms that optimum interpolation is only very slightly better than linear interpolation for daily temperatures over uniform terrain, and also that very

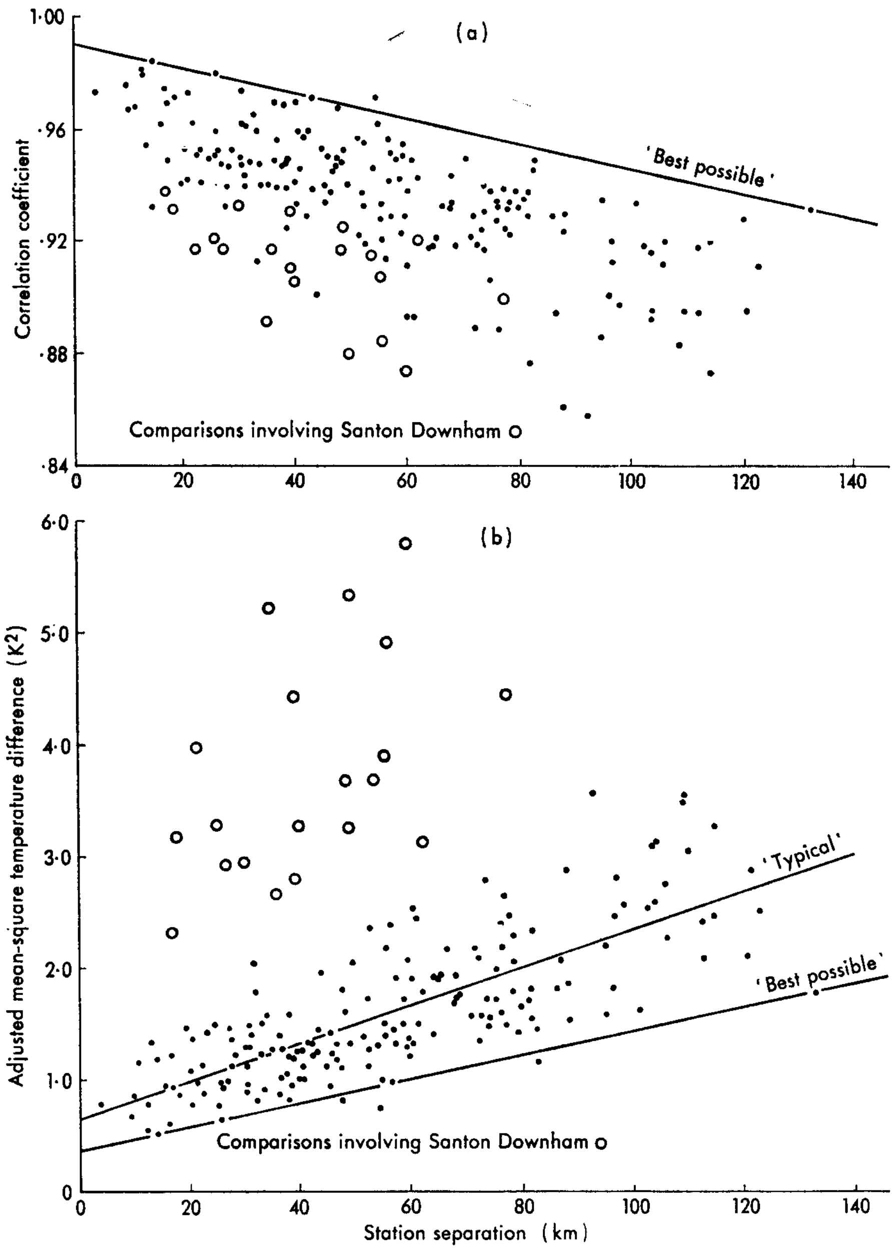

FIGURE 2—CORRELATION COEFFICIENTS (a) AND ADJUSTED MEAN-SQUARE DIFFERENCES (b) BETWEEN WINTER DAILY MINIMUM TEMPERATURES AT PAIRS OF STATIONS IN EAST ANGLIA

TABLE II—COMPARISON OF r.m.s. ERRORS OF INTERPOLATION (K) OF DAILY TEMPERATURES AT MID POINTS BETWEEN (a) TWO STATIONS 100 km APART, AND (b) THREE STATIONS ON A TRIANGULAR GRID OF SPACING 100 km—DERIVED FROM 'BEST POSSIBLE' NETWORK OVER UNIFORM TERRAIN AND GANDIN'S FORMULAE

		Daily maximum temperatures		Daily minimum temperatures	
		Winter	Summer	Winter	Summer
Linear interpolation	(a)	0·50	0·65	0·78	0·79
	(b)	0·49	0·64	0·76	0·75
Optimum interpolation	(a)	0·48	0·64	0·72	0·75
	(b)	0·44	0·62	0·67	0·71

little accuracy is to be gained by interpolating between three stations in a triangular spacing, rather than along a line joining two stations. Further discussion will therefore be based on consideration of linear interpolation in one dimension.

Figure 3(a) shows how the r.m.s. error of linear interpolation within the 'best possible' network varies with station separation. The errors for summer and winter daily minimum temperatures are clearly not significantly different, and are greater than the errors arising from the estimation of maxima. This is to be expected in view of the much greater dependence of screen minima on the nature of the underlying ground surface and immediate local topography. The interpolation error curves for summer and winter maxima are close over short distances and diverge with increasing station separation, with the summer errors being greater than the winter. This may be understood qualitatively by considering that a measured maximum temperature in the summer is much more dependent on the local radiation balance, which in turn is sensitive to changes of albedo arising from differences in soil type and ground cover. In winter, the advective component of the heat balance is more important, spatial differences are naturally smaller and so interpolation errors are also less.

The extrapolation of the curves to zero distance provides an estimate of the r.m.s. differences which might be expected between measurements made from 2 thermometer screens at the same site. Smith (1951) reported results of just such an experiment at Kew, and his results can be compared with those from the present study. His r.m.s. differences were with respect to an assumed 'true' value given by the mean of simultaneous observations, and so to give inter-station differences they should be multiplied by $\sqrt{2}$. It can then be seen from Figure 3 that the Kew r.m.s. difference in maximum temperatures (denoted by X) coincides almost exactly with the extrapolations to zero distance derived from the East Anglian 'best possible' network. That is, accuracy of interpolation between stations is limited purely by the accuracy of the instrument and the reading and recording process. For minimum temperatures, however, the East Anglian extrapolation to zero distance gives a value much higher than the Kew figure (denoted by N), indicating that even with a 'best possible' network over uniform terrain, the inherent variability due to the unique character of each observing site is the limiting factor to interpolation accuracy.

The mean of the daily maximum and minimum temperatures is a close approximation to the mean temperature for the day, and so the r.m.s. error of interpolation of a daily mean temperature can be considered to be half the square root of the sum of the squares of the errors arising from interpolation of the two extremes. The r.m.s. error as a function of station separation in the 'best

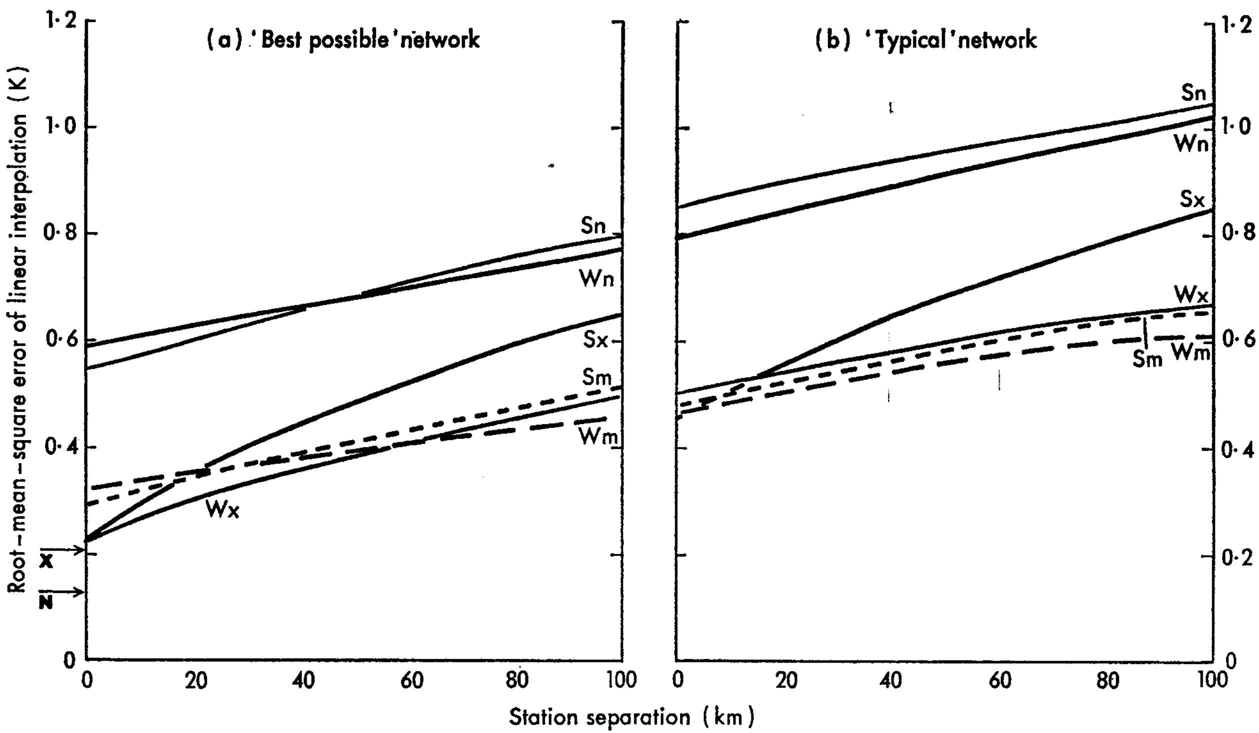

FIGURE 3—ROOT-MEAN-SQUARE ERRORS OF LINEAR INTERPOLATION (K) OF DAILY TEMPERATURES BETWEEN TWO STATIONS OF STATED SEPARATION IN UNIFORM TERRAIN

W—Winter x—Maximum temperatures
S—Summer n—Minimum temperatures
m—Mean temperatures

X and N denote r.m.s. differences between temperatures measured in different screens at Kew for daily maxima and daily minima respectively.

possible' network is shown by the dashed curves in Figure 3(a). The curves for winter and summer are not significantly different.

For network planning purposes it is desirable to know what interpolation errors are likely to arise from a 'typical' rather than a 'best possible' network, and so the 'typical' *S*-function was defined by linear regression of the plotted *S* values on distance, neglecting 'frost hollow' outliers on the minimum temperature plots. Resulting correlations between *S* and distance lay between 0·90 (for summer maxima) and 0·74 (for summer minima) with about 140 pairs. The r.m.s. errors of linear interpolation arising from the *S*-functions so defined are shown in Figure 3(b) and, as in Figure 3(a), appropriate curves for daily mean temperatures have been added. The r.m.s. errors for a 'typical' network are, in general, about 0·15–0·20 K greater than for the 'best possible' network.

Table III shows the station separations necessary to achieve given r.m.s. errors of linear interpolation from a 'typical' network, and it is clear that, in general terms, for daily extreme temperatures over uniform terrain there is little interpolation accuracy to be gained by having a station spacing of less than about 20 km (i.e. a station density greater than about the current national average). For those uniform areas with densities *greater* than this value, some stations can be considered redundant, since a decrease in inter-station separation cannot result in improved interpolation accuracies due to either instrumental (maximum temperatures) or exposure (minimum temperatures) constraints, as discussed earlier. To achieve the same level of interpolation accuracy for daily mean temperatures, the required observing network can clearly be very much sparser.

TABLE III—STATION SEPARATION (km) REQUIRED TO ACHIEVE THE STATED r.m.s. ERROR OF LINEAR INTERPOLATION ON DAILY TEMPERATURES AT MID POINTS BETWEEN STATIONS IN 'TYPICAL' NETWORK IN UNIFORM TERRAIN

	r.m.s. error of linear interpolation (K)					
	0·5	0·6	0·7	0·8	0·9	1·0
Winter maxima	*	50	120	190	280	370
Winter minima	*	*	*	*	40	85
Winter means	15	85	175	275	390	515
Summer maxima	10	30	55	80	115	150
Summer minima	*	*	*	*	20	70
Summer means	10	55	110	180	255	340

* Stated accuracy not attainable with 'typical' network.

ANALYSIS OF SUNSHINE DURATIONS

There were certain problems associated with the analysis of daily sunshine durations in the manner described above for temperatures. The frequency distribution of daily sunshine durations is markedly non-normal, being bounded both below (by zero) and above (by the maximum possible value for the latitude and time of year), and possessing a large contribution from zero values (i.e. sunless days). The procedure adopted to select a suitable sample of days for analysis was as follows. Firstly, only every third day was considered, to ensure synoptic and statistical independence of the sample (although the autocorrelation coefficient of sunshine durations is only about 0·20 for a lag of one day); secondly, each value was expressed as a percentage of the maximum possible duration for the time of year, in order to allow grouping of values from different months; and, thirdly, all values of less than 5 per cent were neglected, to avoid undue weighting of the *R* and *S* calculations by the influence of sunless days. It was considered desirable to perform separate analyses for winter and summer days, and 4-month periods (November–February and May–August) were chosen to provide adequate sample sizes after the above filtering process had been carried out.

As for temperatures, *R* and *S* calculations were performed for all possible station pairs and those values (about 120) derived from more than 50 pairs were plotted versus distance; Figure 4(a) and (b) are the plots for summer data. There is again a well-defined upper (lower) linear bound to the *R*(*S*) plot approximately defining the behaviour of a 'best possible' network, but this linearity cannot be extended below a station separation of about 25 km, since unacceptable intercepts at zero distance would result (i.e. *R* greater than unity, *S* less than zero).

Since the reported daily sunshine duration is the result of a hand-and-eye analysis of the burn on the sunshine card, and there is less immediately 'local' climate influence on sunshine than on temperature (due to soil, ground cover and topography), it might be expected that the station pairs displaying maximum correlation for a given separation are those which attain the highest standards of analysis accuracy. In fact, individual stations do not contribute to the definition of the upper limit to the *R*-function more often than would be expected by chance, and Meteorological Office stations do not, in general, display higher correlations than co-operating stations of the same separation.

The *R* and *S* functions for the 'typical' network have been deduced by linear regression of the plotted values on distance, with resulting correlations of 0·90 and 0·95 for winter and summer, respectively. As for temperatures, the r.m.s. errors of linear and optimum interpolation were compared by inserting the *S*- and *R*-functions into the appropriate Gandin formulae, and Table IV shows that the use of optimum interpolation again gives relatively small improvement in r.m.s. errors over linear interpolation. (The errors have been reconverted from percentage of maximum possible duration to hours by assumption of 9 and 16 hours as typical winter and summer maximum durations respectively.)

TABLE IV—COMPARISON OF r.m.s. ERRORS OF INTERPOLATION (hours) OF DAILY SUNSHINE DURATIONS AT MID POINTS BETWEEN (a) TWO STATIONS 100 km APART, AND (b) THREE STATIONS ON A TRIANGULAR GRID OF SPACING 100 km—DERIVED FROM 'TYPICAL' NETWORK OVER UNIFORM TERRAIN AND GANDIN'S FORMULAE

		Summer	Winter
Linear interpolation	(a)	1·49	1·11
	(b)	1·46	1·09
Optimum interpolation	(a)	1·48	0·99
	(b)	1·44	0·95

The variation with station separation of r.m.s. error of linear interpolation is shown in Figure 5 for the 'typical' network and indicated schematically for the 'best possible' network, since the uncertainty over the behaviour of the *S*-function below 25 km implies that r.m.s. errors for stations less than 50 km apart cannot be calculated with confidence. Except at small station separations, interpolation errors for summer days are greater than for winter days, as might be expected in view of the importance of solar radiation in determining local cloud conditions via surface heating.

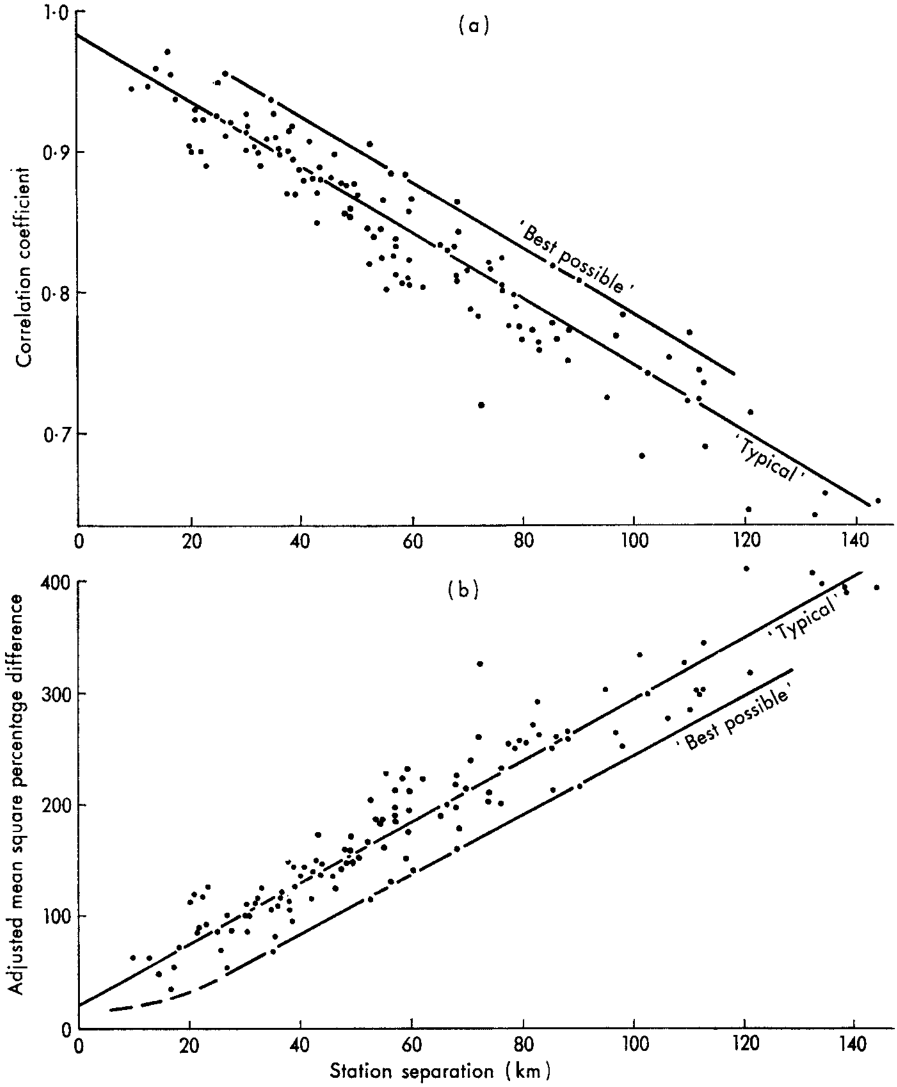

FIGURE 4—CORRELATION COEFFICIENTS (a) AND ADJUSTED MEAN-SQUARE DIFFERENCES (b) BETWEEN SUMMER DAILY SUNSHINE DURATIONS (EXPRESSED AS PERCENTAGE OF MAXIMUM POSSIBLE) AT PAIRS OF STATIONS IN EAST ANGLIA

Because of the difficulty of extrapolating the 'best possible' r.m.s. error curves, it is not possible to compare deduced interpolation errors at zero separation with observed r.m.s. differences between two instruments at the same site. However, it is interesting to note in this context that the quality control applied to sunshine card analyses at Meteorological Office Headquarters allows a r.m.s. difference of about 0·25 hour a day between analyses of the same card by different analysts. This criterion was selected many years ago on the basis of experience, and is clearly not inconsistent with what might be deduced from an extrapolation to

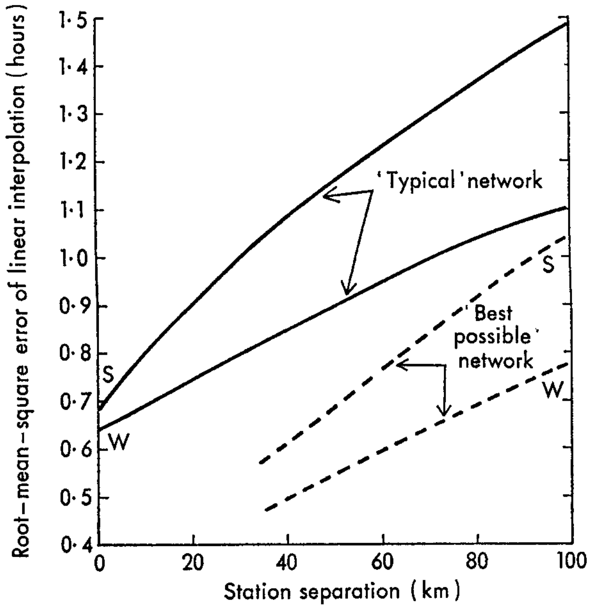

FIGURE 5—ROOT-MEAN-SQUARE ERRORS OF LINEAR INTERPOLATION (hours) OF DAILY SUNSHINE DURATION BETWEEN TWO STATIONS OF STATED SEPARATION IN UNIFORM TERRAIN

W—Winter (9-hour day) S—Summer (16-hour day)

zero distance of the 'best possible' curves in Figure 5. The 'typical' curves imply that stations in general, with the methods of analysis instruction currently in use, are not capable of attaining a r.m.s. difference between analyses of less than about 0·65 hour a day, although some part of this error may be attributable to faulty setting-up of the instrument.

LONGER TIME SCALES

For some application, notably the calculation of evaporation for hydrological and agricultural interests, spatially representative climatic data meaned over a time scale of perhaps a week or more are required. Knowing the r.m.s. errors of interpolation for daily data, it is possible to calculate the corresponding values for n-day means and thus to define the network density required to give acceptable levels of interpolation accuracy on this longer time scale. The standard error, σ_n, of the mean of n consecutive observations in a persistent series is (Brooks and Carruthers, 1953, p. 326):

$$\sigma_n = \frac{\sigma_1}{n^{\frac{1}{2}}}\left[1 + \frac{2r}{1-r}\left(1-\frac{1}{n}\cdot\frac{1-r^n}{1-r}\right)\right]^{\frac{1}{2}},$$

where σ_1 is the standard error of the individual observations and r is the autocorrelation coefficient for a lag of one day.

Autocorrelation coefficients for a lag of one day were computed for each month over a 19-year period at Wittering, and the typical values adopted for use are shown in Table V, along with the derived station separations necessary for given r.m.s. interpolation accuracies for 7-day mean values.

Using the simple approach to potential evaporation (PE) calculations described in MAFF *Technical Bulletin* No. 16 (1967), it is possible to show that an error of 0·4 hour a day in mean sunshine duration over 7 days corresponds approximately to an error of 1 mm (or 5 per cent of a summer average value) in 7-day PE in East Anglia. It can also be shown that an error of 0·5 K in 7-day mean temperature gives rise to a PE error of about 1 mm. These figures, taken in conjunction with Table V, imply that if temperature and sunshine data are available from the same network of stations, then the error in a PE estimate at a point between stations is very much more dependent on the sunshine interpolation error than on the temperature interpolation error. To equalize the contributions to the PE error, the sunshine-measuring network would need to be much denser than the temperature-measuring network.

TABLE V—STATION SEPARATIONS (km) REQUIRED TO ACHIEVE THE STATED r.m.s. ERROR OF LINEAR INTERPOLATION ON 7-DAY MEAN VALUES AT MID POINT BETWEEN STATIONS IN A 'TYPICAL' NETWORK IN UNIFORM TERRAIN

	Typical autocorrelation coefficient (lag = 1 day)	r.m.s. error of linear interpolation			
Temperatures (K)		0·4	0·5	0·6	0·7
Winter maxima	0·65	45	140	260	400
Winter minima	0·60	*	*	50	125
Winter means	0·70	55	170	300	470
Summer maxima	0·50	50	95	160	230
Summer minima	0·35	*	50	160	290
Summer means	0·55	80	180	310	460
Sunshine durations (hours)		0·4	0·5	0·6	0·7
Winter	0·15	55	110	180	265
Summer	0·25	10	35	65	100

* Stated accuracy not attainable.

CONCLUDING REMARKS

The results presented here allow the network planner to assess, in terms of interpolation accuracy, the consequences of increasing or decreasing the density of a temperature- or sunshine-measuring network. The findings obviously apply only to uniform terrain, and the behaviour of the *R*- and *S*-functions in complex topography remains to be investigated. However, these results allow a lower limit to be fixed to the number of stations required to achieve a given accuracy of interpolation at any point within an area.

ACKNOWLEDGEMENT

The programming work for this investigation was undertaken by Mr W. H. Mills.

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REVIEWS

The climate of the British Isles, edited by T. J. Chandler and S. Gregory. 230 mm × 160 mm, pp. vi + 390, *illus.* Longman Group Ltd, Fourth Avenue, Harlow, Essex CM19 5AA, 1976. Price: £5.95.

This book consists of essentially self-contained chapters by 15 authors. This leads to some repetition where the subjects overlap and to a little unevenness of presentation. It is undoubtedly destined to be the most comprehensive single collection of data for a long time to come. It does not, however, make exciting reading; in particular, the relentless description of data, much of which is also presented in tables or diagrams or both, is at times overwhelming.

There are seven chapters on the principal weather elements. They are in the main very thorough and systematic, giving statistics on annual, seasonal and monthly means, fluctuations, extremes and diurnal variations by means of tables and charts for a dense network of stations.

Only here and there did I react sufficiently to something, or to its absence, to comment here. For example, in 'Wind', I was disappointed not to find some account of severe local winds such as the famous Sheffield and Glasgow gales, or of whirlwinds and tornadoes; but this is not a weather book. 'Radiation', 'Temperature' and 'Evaporation, Humidity and the Water Balance' are all efficiently dealt with; the short section on human comfort indices whets the appetite for more. 'Visibility' is concerned almost entirely with fog, rather than the industrial and continental aerosol hazes so common in dry conditions. There is a note on the dramatic improvement in London visibilities since the Clean Air Act of 1956, but also a surprising (possibly unintentional) implication of a 10–11 year cycle in pollution. 'Cloud and Thunder', an odd combination, contains none of the drama of those elements—such things are admittedly awkward to quantify. I feel that much more could and should have been made of this opportunity; surely statistics exist on the occurrence of different cloud types and on the distribution and frequency of lightning discharges? 'Precipitation' is the longest of the chapters, giving amongst much else the elusive answers to such common questions as what are the frequencies of extreme falls, wet spells and droughts. The principal synoptic situations giving rise to frontal, convective and orographic rain are described, though, probably because the data do not exist, there are no figures for the relative contributions from each. Snowfall receives mention in proportion to its occurrence, though in view of its impact on the community I feel that it deserves considerably more. There is no mention of hail.

Four chapters are devoted to regions which might be termed special in some way. Coasts with their sea-breezes and sea fog (e.g. haar), and inland waters, which are mainly too small to have any significant moderating effect, are well treated. Upland climates are considered mainly from the point of view of the restriction of the growing season. 'Topographic Climates' would have benefited from some revision to eliminate a few obscurities and what look like repetitions. Amongst the numerical data here, there is an irritating mixture of units and a mistake or two. 'The Climate of Towns' is an excellent review of urban climates, covering all important environmental elements. 'Regional Climates' seems to add little to earlier material.

'Synoptic Climatology' in a way sets the scene for the whole of the book, describing the large-scale circulation and common weather types over the British Isles. Singularities, persistence of types and seasonal lag relationships are noted, as is the inevitable subject of cycles, solar or otherwise. The possible roles of anomalies of sea temperature and ice cover are mentioned. In this chapter, and even more so in that on 'Recent Climatic Change', the authors are grappling with rapidly evolving subjects, so it is not surprising that much can be found to debate. The bewildering picture of fluctuations of circulation indices and of all the main weather parameters on various time scales leaves the impression that a lot is still to be done in sorting out the signal from the noise; even so, I feel that these two chapters provide a reasonable introduction.

Only half a dozen misprints were noted; among the dozen or so obvious mistakes and omissions, the conspicuous errors in the conversion factors on page 75 are all corrected if $W m^{-2}$ is read as $W h m^{-2}$; on page 76, and subsequently, 'intensity' is wrongly used (should be 'irradiance'); on page 320, the quoted lead content for the London atmosphere must be too high by several orders of magnitude; and in Figure 10.6, the late Ocean Weather Station 'I' is shown in the wrong place.

I found the large, closely spaced, spidery type of the main text rather unpleasing and tiring on the eye, whilst parts of the index and references are in an offendingly bold type. The diagrams, on which the book relies so heavily, though adequate, could have been much better. Some are unnecessarily big and rather more are too small (indeed, a hand lens is a great help for seeing some detail). Most of the contoured diagrams would have been strikingly clarified by shading, and strategically placed labels could have saved much searching amongst the small print of the legends.

There is a very full index and reference list, and the book can be recommended as excellent value for the moderate price.

K. J. BIGNELL

Radiative processes in meteorology and climatology, Developments in Atmospheric Science, 5, by G. W. Paltridge and C. M. R. Platt. 245 mm × 170 mm, pp. xvii + 314, *illus.* Elsevier Scientific Publishing Co, PO Box 330, Amsterdam, The Netherlands, 1976. Price: Dfl 103.00.

Radiative processes play an important role in the meteorology and climatology of the terrestrial environment. The source of energy which drives the weather systems is the radiation received from the sun, while the sink to the system is the long-wave energy to space, regulated by variations in atmospheric opacity due to compositional changes, clouds, aerosols and surface conditions. The importance of radiative effects in climatic variations will require all students of the subject to possess an understanding of the physical processes involved. But radiative transfer is poorly discussed for applied atmospheric physicists in the available texts. Books on general meteorology cover the subject in a single chapter, while the treatises by Chandrasekhar and by Goody, although comprehensive, are thought to be too theoretical. Paltridge and Platt have attempted to provide a text at the level required by experimental atmospheric physicists which has a balance between basic physical processes and their mathematical representations. I believe this book has been quite successful in reaching this objective, but fails in omitting to provide detailed critical discussions which are an invaluable aid to readers when choosing between various theoretical methods and parametrizations.

The subject matter of the book is covered in 10 chapters, supplemented by some useful appendices. The initial three chapters provide a suitable introduction to the subject, covering the basic properties and terminology. Like many books I have read so far, this text seems to treat experimental data as if they possessed accuracy. For example, in discussing the characteristics of the models used to study the radiation budget of the earth, no comment is made on the possible uncertainties in the cloud data which form an essential ingredient of thedy stu

Chapter 4 introduces the reader to the mathematical description of radiative transfer for single scattering of radiation by cloud/aerosol particles and then the development of multiple scattering methods. It is surprising that the authors have omitted to discuss the scattering of radiation by irregularly shaped particles, particularly cylindrically shaped objects which are important in ice clouds. The discussion of the numerical methods is brief and disappointingly sketchy, and the authors have missed an excellent opportunity here to use some physical insight when discussing those techniques which would be valuable when constructing simpler parametrizations later in the book.

The next set of chapters takes us through the effects of solar radiation in the atmosphere (Chapter 5), Radiation at the Ground (Chapter 6), Long Wave Radiation in the Clear Atmosphere (Chapter 7), Clouds and Long Wave Transfer (Chapter 8), and Atmospheric Aerosols (Chapter 9). The discussions of the topics are reasonably comprehensive, but the examples used to illustrate the discussions are almost all taken from theoretical predictions. The reader would have no idea of the accuracy of the methods or their ability to reproduce measurements. How can anyone draw conclusions on the suitability of theoretical methods in the absence of experimental data?

The final chapter on Radiation and General Dynamics adequately covers the problems of radiative equilibrium, radiative convective equilibrium, radiation within the boundary layer, and the interaction between radiation and the formation of clouds. But why did the authors omit any detailed discussion of the role of radiation in the general circulation of the atmosphere? The title of their book implies its presence.

After reading the book and studying certain aspects of it in detail, I looked again at the authors' purpose in writing the text. They suggested that the book would be aimed at experimental atmospheric physicists in order to provide them with an understanding of radiative processes. Certainly they have had some measure of success in providing a reasonably good description of the theoretical methods. But the omission of experimental data with which to verify the methods or aid the discussion is very odd. Furthermore, as I have previously pointed out, the absence of certain topics seems to suggest that the book may be misnamed. In spite of these misgiving, it is a timely and useful book which the specialist will find to be a useful addition to his bookshelf.

G. E. HUNT

The climate of Japan, Developments in Atmospheric Science, 8, edited by E. Fukui. 250 mm × 170 mm, pp. ix + 317, *illus.* Elsevier Scientific Publishing Co, PO Box 330, Amsterdam, The Netherlands, 1977. Price: $52.95, Dfl 130.00.

This is an unusual subject to appear in a series on 'Developments in Atmospheric Science', but nevertheless the book is a useful addition to the very limited literature in English on the climate of Japan. It consists of 13 chapters by eight authors which cover the synoptic and physical climatology of Japan, its climatography, and aspects of climatic change and local climate.

Inevitably in a book of this nature there are variations of style and approach by the different authors, so that the two introductory chapters have a strong environmental bias stressing the diversity of Japan's climate and the effect of the seasons on the life of the people. This is not followed by an examination of individual climatic elements as might be expected from the title, but, instead, by the synoptic seasons of Japan—the winter monsoon, the Bai-u rains, the midsummer dry spell, and the typhoons and Shûrin—are examined in considerable detail.

Climatic elements are discussed in the chapters on the heat balance, the water balance and flow patterns, though these titles are misleading as the amount of space given to the heat-balance components is relatively small compared to that on temperature, precipitation, sunshine and the radiation balance. There is a brief chapter on air pollution and urban climate, followed by a long section on the climatography of Japan and its climatic divisions, with a concluding chapter on climatic fluctuations which covers the period from the Quaternary to recent changes.

With such a large amount of information, the book undoubtedly achieves its objective of providing an English language monograph on the climate of Japan. It is much more extensive than the section in 'World Survey of Climatology', Volume 8 (*Climates of Northern and Eastern Asia*), by the same publishers, and it does have an up-to-date approach to the subject. Also in its favour, the book is nicely produced and printed, with the diagrams being generally clear although some suffer through excessive reduction (Japan is not a convenient shape for book diagrams), and a few have deficient or incorrect keys. The style of English is very good, although the reviewer had some initial problems over the term 'decade' referring to a 10-day period rather than its more usual meaning. The amount of duplication between chapters is small, apart from unavoidable overlap on the circulation.

One serious omission is an adequate locational map for places mentioned in the text. Many climatological stations are in towns which are too small for a standard atlas but, despite a geographic index, no reference is made to their precise location. Surprisingly, no comment is made about satellite observations despite the claim that this is an up-to-date monograph. It is certain that greater insight into the circulation features of the area around Japan has been gained through the improved spatial coverage provided by these instruments. Less surprising is the lack of reference to publications in English about Japan; for example, *The water balance of monsoon Asia*, by M. M. Yoshino, does not receive any reference in the chapter on the water balance.

However, these are small criticisms and, in general, the book is likely to remain a useful work of reference about the climate of Japan for many years to come.

P. A. SMITHSON

AWARD

We note with pleasure that the twenty-second International Meteorological Organization Prize for outstanding work in meteorology and in international collaboration has been awarded this year to Dr George P. Cressman, Director of the National Weather Service of the National Oceanic and Atmospheric Administration (NOAA) of the United States of America.

NOTES AND NEWS

Secondment of Dr G. E. Hunt

Dr G. E. Hunt, of the High Atmosphere Branch, has been seconded from the Meteorological Office to take charge of the new Laboratory for Planetary Atmospheres in the Department of Physics and Astronomy, University College, London.

ANNOUNCEMENT

Readers of Meteorological Office Scientific Paper No. 36—*A computer-based model for design rainfall in the United Kingdom*, by J. F. Keers and P. Wescott (Met O 900)—should know that there is a mistake in the printing of equation i of Table I on page 3. The following is the correct version:

$$\log M_{5,\,\mathrm{D})} = \log D + \log (A_{48}/48) + \\ + \log (721/1 + 15D) \log (48A_1/A_{48})/\log(721/16).$$

The error occurred solely in the presentation of the equation and does not affect the calculations.

OBITUARY

We regret to record the death on 3 May 1977 of Miss J. M. Noad, Higher Scientific Officer, London/Gatwick Airport. Miss Noad was well known for her athletic achievements in the field of tricycling and was awarded the George Simpson Cup by the Meteorological Office Social and Sports Club in 1971. Before working as a forecaster she had spent some years in the Research Directorate at Bracknell.

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CONTENTS

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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