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MONTHLY AND ANNUAL TOTALS OF RAINFALL REPRESENTATIVE OF KEW, SURREY, FROM 1697 TO 1970

By B. G. WALES-SMITH

Summary. Values of rainfall representative of Kew have been tabulated for each month from 1697 to 1970. Details are given of the method of obtaining the representative values from the available data. Some gaps in the series have been filled by an analysis of a weather diary for Richmond.

Introduction. Routine rainfall measurements have been made at Kew from 1871 onwards. The potential value of a very long rainfall record for one station was thought sufficient to justify an attempt to estimate the annual and monthly falls on the site of Kew Observatory before 1871.

Available data. The earliest 'London area' rainfall records, known to the Meteorological Office, for a complete year are for Upminster in 1697 and from that year onwards, with an unfortunate break from 1717 to 1724 (inclusive), records for one or more London stations at a time are available. Luckily, George Smith, Proctor to Queen Anne, maintained an excellent weather diary[1] at Richmond Palace from 1713 until his death in 1745 and it has been possible to make rough estimates of monthly falls from his descriptions of weather. The numerical data used are those published by Brazell,[2] but some estimates have been made to obtain a series representative of Kew over the whole period 1697–1970. (See Appendix I.) The vast majority of the data are recorded in inches and these units have been retained in this analysis (1 in = 25·4 mm).

Analysis and adjustment of data.
1697–1716. The Upminster values have been multiplied by 12/11 = 1·0909 (the approximate relationship between the 1916–50 annual average rainfalls for Upminster and Kew).

1717–24. The Richmond diaries were used to obtain an estimate of monthly rainfall from 1717 to 1724. The diaries overlap the Upminster record from 1713 to 1716, the Fleet Street record from 1725 to 1735 and the Tonbridge record from 1736 to 1744. The Fleet Street record was accepted as an estimate for Kew, and the Tonbridge values were multiplied by 0·876 to obtain an estimate for Kew.

George Smith's diaries give a summary of each month's weather and, for most months, notes on days which the diarist seems to have thought specially important.

For the 20-year period 1725–44 George Smith's descriptions in respect of precipitation were listed, month-by-month, in abbreviated form. Thus, for example, 'Dry 3' would mean 'Dry with three rain days specifically mentioned' and 'NM4' would mean 'No precipitation mentioned in the summary but four days with precipitation listed *below* the summary'.

The Fleet Street or adjusted Tonbridge monthly estimates of Kew rainfalls were written against the descriptions for each year, month-by-month, and the descriptions were then grouped (for each month) on the basis of 'precipitation type' and rainfall amount. Amounts in each group were averaged and the number of cases per average was noted. Table I gives the final classification or 'scale.'

TABLE I—THE CLASSIFICATION OF ENTRIES IN THE RICHMOND DIARIES

	Estimated monthly rainfall *inches*	Number of cases
January		
Very dry, very fine	0·54	2
Dry, little rain	0·78	5
NM(0–3)	0·41	3
NM>4	2·19	3
Part month stormy	1·44	2
Wet, stormy	3·03	5
February		
Extremely dry	0·10	1
Dry, fine, little or no rain	0·66	3
NM(0–3)	0·91	4
Some or occasional precipitation	1·45	6
Wintry with snow, good deal of snow	2·71	2
Wet, stormy	1·57	3
Very wet, great deal of rain	1·92	2
March		
Nil	0·05	1
Almost nil	0·10	1
Dry, generally dry	0·47	2
NM(0–5)	1·76	7
Showery	2·10	1
Some or occasional rain	1·72	4
Wet	2·65	4
April		
Very dry	0·53	1
Dry, very little rain	1·10	4
NM(0–3)	2·88	2
Showery	1·91	7
Partly showery, partly stormy	0·94	3
Some rain, thundery	2·15	2
Wet	3·47	1
May		
Exceedingly or very dry	0·47	2
Dry	0·79	2
Dry with thunder	1·63	1
Some rain	1·49	3
Showery	2·20	8
Wet, very wet	3·38	3
NM(0–3)	1·38	1
June		
Fine	0·92	1
Very little rain	1·39	3
Some rain or showers	1·83	6
Showery	2·84	5
Wet, good deal of rain	2·89	3
Extremely wet, some heavy rains	4·33	2

TABLE 1—*cont'd*

	Estimated monthly rainfall *inches*	Number of cases
July		
Very dry, dry	0·97	5
Some showers of rain or hail	1·95	6
NM	0·74	1
Showery	1·89	4
Very showery, heavy rains, good deal of rain	3·98	3
Wet	0·75	1
August		
Extremely dry, very dry	0·09	2
Dry, little rain	0·30	3
Seasonable some rain, some storms, dry but some rain	1·59	4
Occasional showers	1·73	1
Showery	2·93	3
Several wet days, wet, very wet, very stormy	2·12	4
Some heavy rains	3·39	3
September		
Dry	0·34	2
NM(0–3)	1·89	2
NM≥4	2·94	1
Some rain, generally fine	1·53	5
Partly wet	3·05	4
Rainy, wet, very wet	3·41	5
Showery	1·37	1
October		
Fine, dry, little rain	1·14	4
Mostly dry	1·33	2
NM(0–3)	1·68	3
NM≥4	2·09	1
Showery, stormy	1·91	2
Some rain	2·47	2
Wet	3·01	4
Very wet	4·57	2
November		
Nil	0·40	1
Very dry	1·31	1
Dry	1·34	4
Mostly dry, some rain, partly stormy	2·02	8
NM(0–3)	1·29	4
NM≥4	3·67	2
December		
Very fine	0·53	1
NM(0–3)	1·13	4
NM≥4	1·2	2
Partly wet	1·74	6
Wet, very wintry	2·98	6
Very wet	4·27	1

The scale was used to assess the monthly falls for 1725–44 from the diaries and also to assess the monthly falls for 1713–16, a four-year period deliberately left out of the classification exercise. These monthly estimates were totalled, year-by-year, and are compared with the Upminster – Fleet Street – Tonbridge estimates for Kew in Figure 1. It will be seen that the totals for 1725–44 were 'reconstituted' quite well and that 3 out of 4 of the 1713–16 totals (plotted as crosses) were also well estimated. The year poorly-estimated was the first

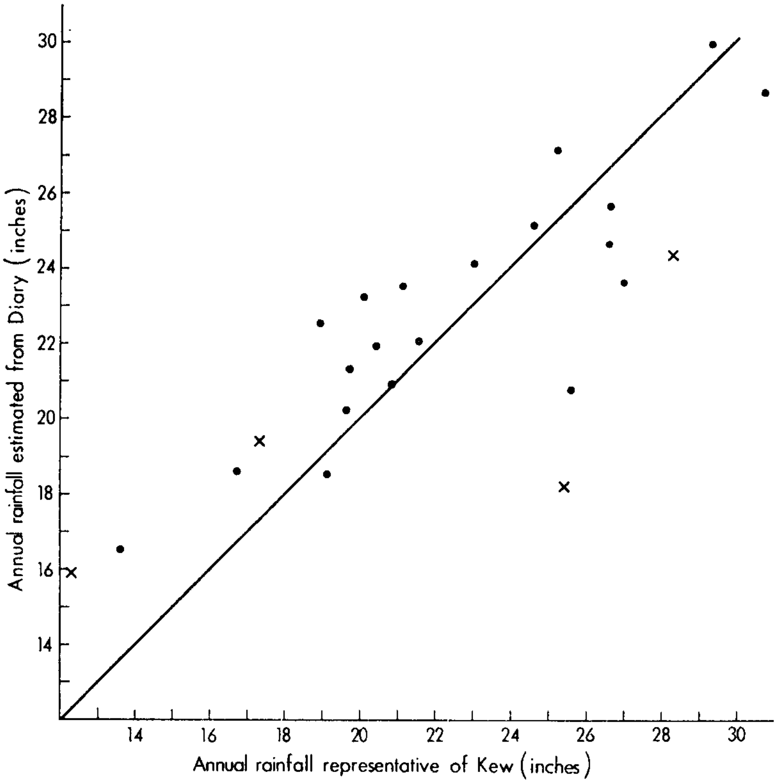

FIGURE 1—THE RELATION BETWEEN DIARY-BASED ESTIMATES AND REPRESENTATIVE MEASUREMENTS FOR KEW FOR 1713–44

x indicates totals for 4 years excluded from the Diary classification
The line represents exact correlation.

of the diary. Little more than this slight support can be given for the method except to say that these very good diaries, treated in the manner described, appear capable of identifying the majority of very wet, wet, average, dry and very dry years, correctly, in relation to average.

The next step was to use the 'scale' and the diary accounts for the period 1717–24 to estimate monthly falls and to total the monthly estimates for each year. The yearly totals are set out in Table II where they are compared with George Smith's *annual* summaries which were not used or even examined when making the scale.

It will be seen that there is an encouraging measure of agreement between the annual totals of monthly estimates and the annual summaries.

1725–35. The Fleet Street values have been accepted since

(i) they are a London record,

(ii) the correlation coefficient for the seven-year overlap with Tonbridge is very high (Figure 2*(a)*) (0·946), and

(iii) if the long-period relationship between Tonbridge *(T)* and Greenwich ($G = (24/27{\cdot}4)\,T = 0{\cdot}876T$) is extracted from the diagram

TABLE II—COMPARISON OF ANNUAL TOTALS OF MONTHLY RAINFALL AT KEW*

Year	Total of monthly estimates *inches*	Annual summary
1717	22·90	None.
1718	22·60	'The *sumer was very hott & dry*. extr: good grapes very little other good fruit 2d. crops white figs ripe. harvest very forward, all got in begin: Septr. *Extr: mild winter.*'
1719	17·70	'This *Sumer was very hott & dry*, good grapes, no other fruit. The Second crop of figs ripe at Michas. *very mild dry winter. water very low.*'
1720	25·80	'The *Sumer wet & green*, little good fruit. Grapes late ripe but some good. *Winter warm & wet.* no frost. mildest Season ever known.'
1721	23·70	None.
1722	18·80	'*Wet Sumer, fair fine Autumn.* very good grapes *fine fair mild dry winter.*'
1723	14·60	'*Longest Sumer ever known. very dry* good grapes 2d. crop of figs, some blew, ripe: *dry warm winter*, 3 weeks at Xtmas fine weather as April.'
1724	21·00	'*Very long Sumer* good grapes, 2d. crop figgs ripe in Septr. *great plenty all sorts fruits* especially Apples and pears tho' no good pears, *fine winter, dry till lately.*'

* Estimated from George Smith's monthly weather diary entries with the same diarist's annual weather summaries as quoted in Britton,[1] phrases relevant to the present paper being italicized.

on page 127 of *London weather*[2] and if Fleet Street and Greenwich Observatory are regarded as probably broadly comparable the dashed 'regression' line shown in Figure 2*(a)* is obtained for comparison with the calculated regression between Fleet Street and Tonbridge. The dashed line is a tolerable fit for the seven points.

1736–64. The Tonbridge values have been multiplied by 0·876. The adjustment could have been made by using the regression equation with Fleet Street but it was felt that such a relationship, based on only a seven-year overlap, was unlikely to be superior to adjustment by proportion of long averages, a well-tried method in rainfall studies. A four-year record is also available for Chelmsford (1738–41) but the long Tonbridge record was preferred.

1765–81. The Lambeth values have been accepted, being a London record without overlap. The overlap of only five years (1787–91) of South Lambeth and Somerset House (Figure 2*(b)*) gives a correlation coefficient 0·924 but it can be seen (Figure 2*(d)*) that Somerset House was poorly correlated with Greenwich (1815–40) and only slightly better correlated with Edmonton (Figure 2*(g)*) (1817–39). Greenwich and Edmonton (Figure 2*(e)*) had a correlation of only 0·753 for almost the same period (one extra year included). On this basis no use could be made of the one-year overlap of Lambeth with South Lambeth in 1782.

1782. The mean of Lambeth and South Lambeth values was accepted.

1783–91. The South Lambeth values have been accepted since

(i) they are a London record, and

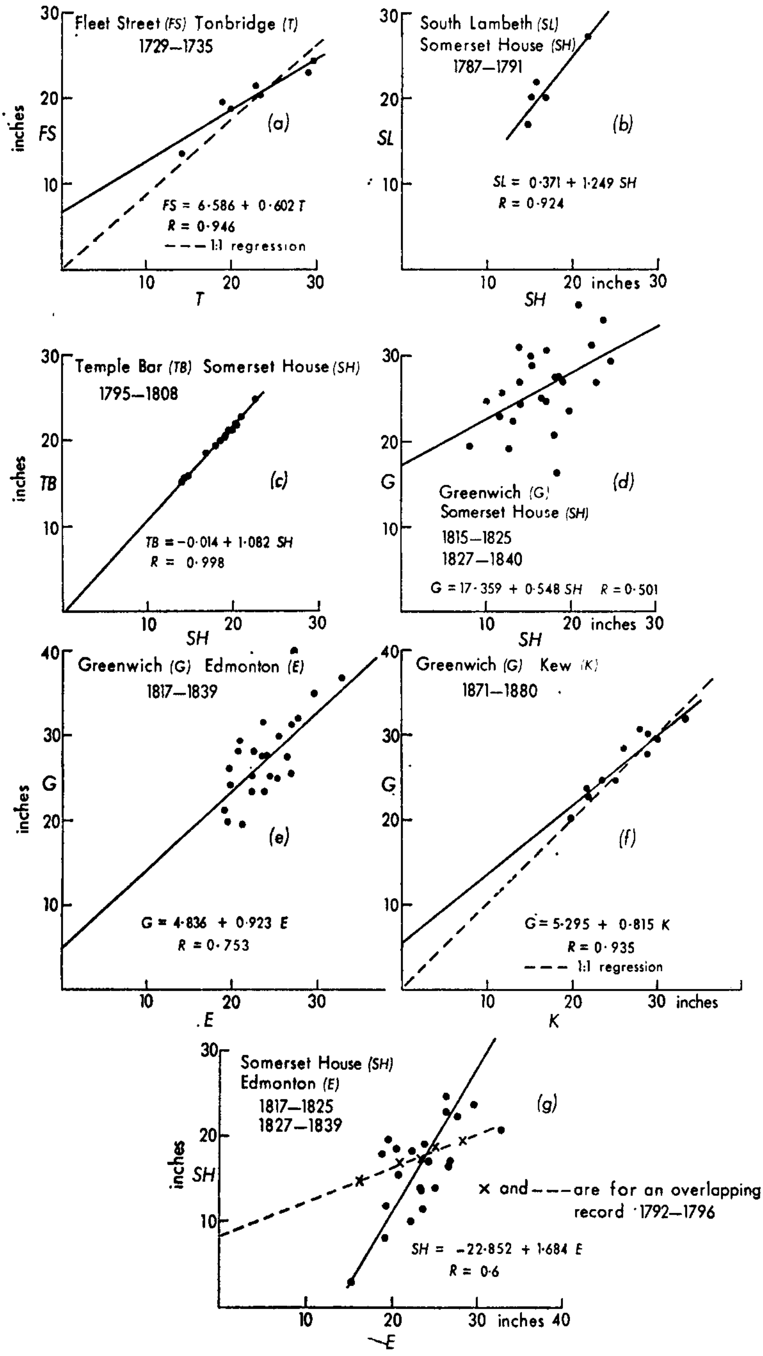

FIGURE 2—REGRESSION LINES BETWEEN VARIOUS PAIRS OF RAIN-GAUGES

(ii) for the period 1787–91 (Figure 2*(b)*) they are very well correlated with Somerset House (0·924) even though the latter record was obtained from a roof gauge!

1792–1809. The regression line for South Lambeth and Somerset House 1787–91 (Figure 2*(b)*) passes very close to the origin and there is little to choose between the slope of the line (1·249) and the direct proportion (obtained from the averages for the period) $SL = 1{\cdot}266\ (SH)$.

As may be seen from Figure 2*(c)*, Temple Bar and Somerset House annual totals were extremely well correlated during the period 1795–1808, strongly suggesting that both were good records. The Somerset House values have been multiplied by 1·266.

1810–13. The Soho Square values have been accepted since

(i) they are a London record, and

(ii) the correlations between Greenwich and Somerset House (Figure 2*(d)*) (1815–40) 0·501, between Greenwich and Edmonton (Figure 2*(e)*) (1817–39) 0·753 and between Somerset House and Edmonton (Figure 2*(g)*) (1817–39) about 0·6, show that from 1815 to 1840 if one of the records was a good one it would have to have been the Greenwich record. The values from the earlier overlapping record (1792–96), added as crosses to Figure 2*(g)*, have a very high correlation *by themselves* and a regression line $SH = 8{\cdot}3 + 0{\cdot}390\ E$ very different from the longer, later record.

The view that the Greenwich record was good is supported by the 0·935 correlation between Greenwich and Kew for the period 1871–80 (Figure 2*(f)*). All this suggests that the previously reliable Somerset House record deteriorated some time after 1808.

The four-year Soho Square record is probably to be preferred to the fragmentary Edmonton and Somerset House values for 1811–14 and gives the only available value for 1810.

The decision to accept the Soho Square totals is supported, to some extent, by considering the available choices. The Greenwich and Kew records are well correlated (0·935 for 1871–80). The correlation between Edmonton and Greenwich for 1817–39, 0·753, is not good and, if the corresponding regression (Figure 2*(e)*) is applied to the 1811 Edmonton total (27·90 in) the value is increased to 30·59 in, far higher than the corresponding Soho Square total. The correlation between Greenwich and Somerset House for the two periods 1815–25 and 1827–40 is very poor (0·501) and if the improbable-seeming regression (Figure 2*(d)*) is applied to the 1812 and 1813 Somerset House values they are tremendously increased. If, on the other hand, the factor 1·27 (approx.) is adopted, (the factor used to adjust values for Somerset House for the period 1792–1809), estimates are obtained close to the 1812 and 1813 measurements at Soho Square. The comparisons are shown in the following table.

	Soho Square	Greenwich (from Edmonton)	Greenwich (from Somerset House)	Kew (from 1·27× Somerset House)
			inches	
1811	22·66	30·59		
1812	25·80		27·41	23·22
1813	20·46		26·11	20·21

1814.* The Somerset House value was multiplied by 1·5. As already noticed, there are sound reasons to suspect that the Somerset House record was deteriorating. The factor 1·27 was accepted as reasonable for 1812 and 1813. The factors relating Somerset House to Greenwich from 1815 to 1819 are: 1815 1·73, 1816 1·98, 1817 1·90, 1818 2·21 and 1819 2·27; 1·5 is simply the mean of 1·27 and 1·73.

1815–70. The two recent 35-year annual averages for Kew and Greenwich Observatories are :

	Kew	Greenwich
	inches	
1881–1915	23·8	23·5
1916–50	23·95	24·00

The comparison for the first 10 years of the overlap (1871–80) gave the correlation coefficient 0·935 (Figure 2*(f)*) and the 10 points are almost as well fitted by the 1:1 regression line as by the calculated line. The Greenwich values have been accepted, without adjustment, as estimates for Kew.

Estimation of monthly totals for years with only annual totals or with annual and only some monthly totals. Estimates were required for the years 1704, 1706, 1707, 1709, 1710, 1711, 1712, 1713 and 1714. Monthly totals for years with only annual totals were estimated by means of the monthly percentages of annual average for Kew for the period 1916–50. Missing monthly totals for years with annual totals and some monthly totals were estimated as follows :

(i) (Annual total) — (available monthly totals) = x in.
(ii) Express x as a percentage (y) of annual total.
(iii) Subtract y from 100.
(iv) For the missing months total the monthly Kew percentages of the annual average (1916–50).
(v) Evaluate $(100 - y)$ — (total of Kew percentages for missing months).
(vi) Divide result obtained in (v) by number of 'missing months' and apply result (plus or minus) to the Kew monthly percentages before using them to apportion the residue of the annual total of rainfall between months without known totals.

For the years 1713 and 1714 monthly estimates were available from the 'scaling' of the Richmond diaries. These were expressed as percentages of their own annual totals and the percentages were then applied to the adopted annual totals to obtain monthly estimates.

The records for a few years (1776, 1782, 1784, 1785 and 1786) each contain an accumulated total for two or three months. These accumulations have been shared equally between the months except in the case of 1782 where two records were available, one complete and the other containing a three-month accumulated total.

* Brazell[2] (p. 164, Note (g)) mentions that the 1814 total recorded by another gauge, a few feet away and 11 ft 6 in lower, appears to have been 20·72 in. This fragment of evidence further supports the view that the catch of the roof gauge was seriously low. It is interesting, though probably coincidental, that 20·72/16·32 = 1·27, the factor used to adjust the 1792 to 1809 record. A fragmentary record by Luke Howard in Middlesex gives a total of 26·07 in for 1814, 1·6 times 16·32, giving some support to the choice of 1·5 as the adjusting factor for 1814.

Comparison of the estimated and measured rainfalls for Kew Observatory with general annual values for England and Wales. In the eighteenth century and the early years of the nineteenth century there were very few rainfall stations in England and Wales. Early general annual values must, therefore, be used with some caution. By the middle of the nineteenth century, however, there were over 1000 gauges in use in the British Isles. Annual general rainfalls for England and Wales are set out in Appendix II.

Monthly rainfall averages for England and Wales, expressed as percentages of monthly averages for the 35-year period 1881–1915, were published in *British Rainfall 1931*, in an article by F. J. Nicholas and J. Glasspoole.[3] The article gives the number of stations used for each year's estimates and these may be summarized as follows :

1727–66	2–4
1767–87	3–9
1788–1820	6–17
1821–49	19–28
1850–67	43–58

The annual values reproduced in Appendix II and their component monthly values have been kept up to date in the Meteorological Office under the supervision of J. Grindley and they exist as a computer print-out and as a KDF 9 magnetic-tape record.

Figure 3*(a)* compares general England and Wales values *(EW)* and the estimated Kew annual values *('K')* for 1727–1814; Figure 3*(b)* compares general England and Wales values and the Greenwich Observatory annual values *(G)* for 1815–70; Figure 3*(c)* compares general England and Wales values and the Kew Observatory annual values *(K)* for 1871–1970.

Regression equations and correlation coefficients *(R)* are :

1727–1814	$EW = 14{\cdot}446 + 0{\cdot}8089\ 'K'$	$R = 0{\cdot}6427$
1815–1870	$EW = 15{\cdot}946 + 0{\cdot}7616\ G$	$R = 0{\cdot}8032$
1871–1970	$EW = 15{\cdot}874 + 0{\cdot}8471\ K$	$R = 0{\cdot}7468$

It will be seen that all three equations are very much alike, especially the most recent pair. The improvement in the correlation is, presumably, due to (i) the use of a single (observatory) record after 1815 and (ii) the increase in density and representativeness of the England and Wales network during the early part of the nineteenth century.

Table III gives 35-year average rainfalls for (*a*) the estimated and measured values for Kew, and (*b*) England and Wales, and expresses the first set as a percentage of the second. The percentages have decreased since the 1811–45 period, presumably because of the removal of 'London and Home County bias' from the general values. Table IV examines the relationship in terms of 10-year averages and shows the same decrease of percentage. Figure 4 shows the Kew 10-year falls as percentages of 7/10 of the England and Wales values and compares the two sets of values directly.

Future plans. The monthly and annual rainfalls of Appendix I have been transferred to punched cards. An analysis scheme has been designed and programmed in FORTRAN and has provided statistics relevant to flooding, rainfall deficiency and aquifer recharge. Various other uses are being made of the series.

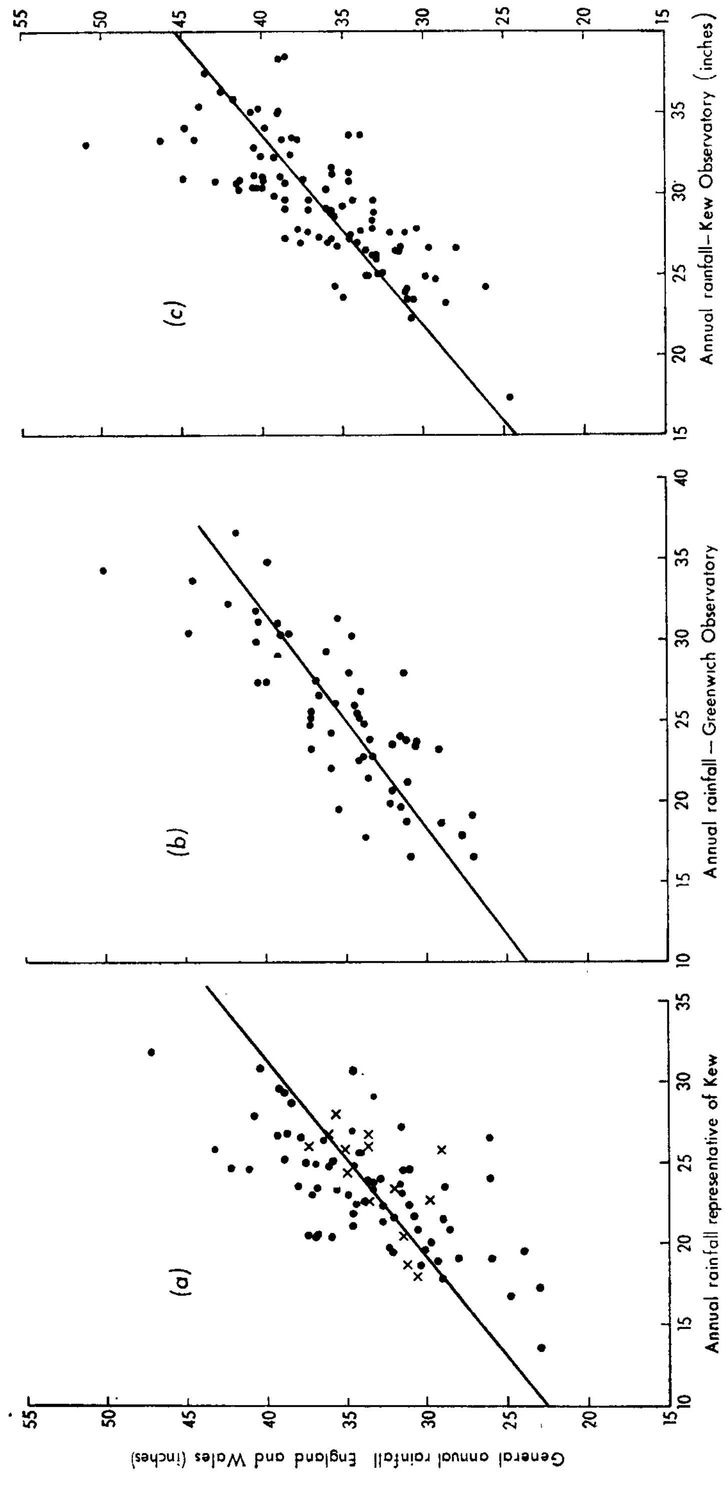

FIGURE 3—THE RELATION BETWEEN THE GENERAL ANNUAL RAINFALL FOR ENGLAND AND WALES AND THE ANNUAL RAINFALL (*a*) REPRESENTATIVE OF KEW (PERIOD 1727–1814), (*b*) FOR GREENWICH OBSERVATORY (PERIOD 1815–1870) AND (*c*) FOR KEW OBSERVATORY (PERIOD 1871–1970)

TABLE III—35-YEAR AVERAGE RAINFALL

35-year period	(*a*) Representative of Kew	(*b*) England and Wales	Percentage, (*a*) of (*b*)
1706–1740	22·46 (570·5)	—	—
1741–1775	23·79 (604·3)	33·65 (854·7)	70·7
1776–1810	23·32 (592·3)	33·43 (849·1)	69·7
1811–1845	25·80 (655·2)	35·42 (899·7)	72·8
1846–1880	24·59 (624·6)	35·82 (909·8)	68·6
1881–1915	23·79 (604·3)	35·24 (895·1)	67·5
1916–1950	23·95 (608·3)	36·53 (927·9)	65·6

Note : Rainfall amounts are given in inches with millimetre equivalents below in brackets.

TABLE IV—10-YEAR AVERAGE RAINFALL REPRESENTATIVE OF KEW OBTAINED FROM ADJUSTED AND MEASURED VALUES

Decades	Rainfall *inches*	Percentage of total for England and Wales
1701–10	21·98	—
1711–20	22·42	—
1721–30	21·74	—
1731–40	22·96	72
1741–50	21·90	73
1751–60	23·89	70
1761–70	24·95	70
1771–80	24·26	71
1781–90	22·89	69
1791–1800	23·24	67
1801–10	23·71	72
1811–20	25·95	76
1821–30	28·20	77
1831–40	23·55	67
1841–50	24·19	67
1851–60	25·00	73
1861–70	23·32	69
1871–80	26·14	67
1881–90	23·40	66
1891–1900	22·49	65
1901–10	24·13	69
1911–20	26·77	71
1921–30	24·38	65
1931–40	23·41	64
1941–50	22·63	65
1951–60	24·14	65
1961–70	23·95	67
Mean of 24 decades	24·14	
Mean of 27 decades	23·91	

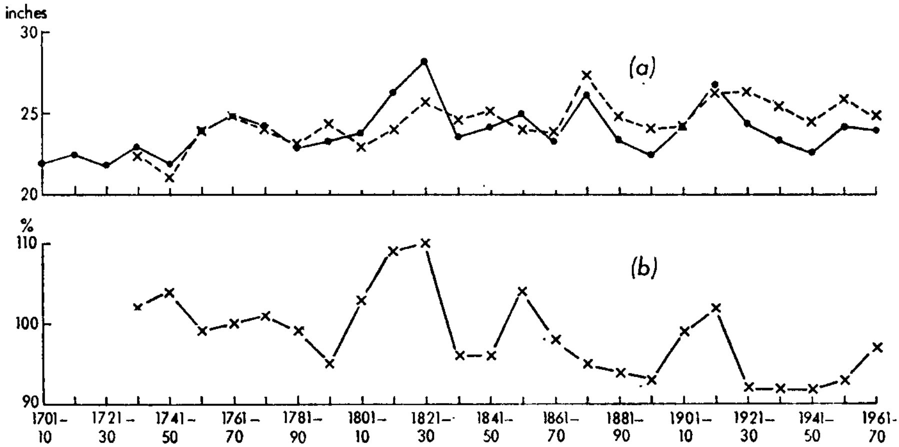

FIGURE 4—10-YEAR RAINFALLS : *(a)* KEW WITH 0·7 × ENGLAND AND WALES *(b)* KEW AS PERCENTAGE OF 0·7 × ENGLAND AND WALES

.——. Kew rainfall x – – – x 0·7 × England and Wales

Acknowledgements. The writer wishes to thank Messrs H. H. Lamb and A. Bleasdale for reading an early version of the text and for encouragement and helpful comments. A list of early documents, prepared by Mr A. B. Smith of the Meteorological Office Library, Bracknell, drew the writer's attention to George Smith's diaries.

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Appendix I

Monthly and annual totals of rainfall representative of Kew, 1697–1970 (in inches).

1697–1716 Upminster × 1·0909

*Monthly totals for 1706, 1709–12 and for certain asterisked months in 1704, 1707 are obtained by the use of the monthly percentages of the annual average for Kew for the period 1916–50.

Adjustments to mean percentages were made where some measured monthly totals were available (see page 352).

†Monthly totals for years 1713, 1714 were apportioned from the annual totals by using the Richmond diaries.

1717–24 ‡Monthly and annual totals estimated from Richmond diaries (see page 345).

1725–35	Fleet Street
1736–64	Tonbridge × 0·876 (Note : September 1752 has only 19 days. The period 3–13 September inclusive was dropped at the change of calendar)
1765–81	Lambeth
1782	Mean of Lambeth and South Lambeth
1783–91	South Lambeth
1792–1809	Somerset House × 1·27
1810–13	Soho Square
1814	Somerset House × 1·5
1815–70	Greenwich Observatory
1871–1970	Kew Observatory

Note : In the period 1776 to 1786 values marked '+' are monthly totals obtained by sharing accumulated totals evenly between months except in 1782 when likely proportions were given by one of the two records used in the estimate (see page 352).

	1697	1698	1699	1700
January	0·79	2·40	1·95	0·86
February	0·39	0·28	1·33	1·68
March	0·59	2·05	1·23	0·34
April	1·65	1·77	0·75	1·67
May	0·70	2·64	0·59	1·52
June	1·08	1·92	0·96	1·67
July	1·35	3·73	1·45	0·93
August	3·07	1·54	1·88	1·78
September	2·29	2·65	1·77	3·25
October	1·84	2·87	2·95	3·75
November	1·23	3·69	0·43	1·15
December	2·04	1·29	1·28	2·26
Total	17·02	26·83	16·57	20·86

	1701	1702	1703	1704	1705	1706*	1707	1708	1709*	1710*
January	3·27	2·15	1·95	0·89	0·24	2·37	1·03*	3·14	2·59	1·79
February	1·93	1·60	1·41	0·48	1·21	1·70	0·59*	0·50	1·86	1·29
March	0·86	0·52	1·04	3·51	1·22	1·62	0·54*	2·21	1·78	1·23
April	0·32	2·39	2·74	1·19*	1·13	2·02	0·80*	1·05	2·21	1·53
May	2·00	1·42	4·55	1·19*	0·45	2·02	1·15	2·20	2·21	1·53
June	1·27	2·96	3·19	1·12*	0·72	1·92	1·46	2·53	2·10	1·45
July	2·08	0·96	3·27	1·63*	1·22	2·72	1·39	1·21	2·97	2·05
August	1·44	1·51	0·74	1·48*	2·37	2·48	2·38	3·22	2·71	1·87
September	1·23	1·77	3·26	1·31*	0·45	2·21	3·16	1·59	2·42	1·67
October	2·24	1·73	2·09	1·50*	3·51	2·50	1·44	0·25	2·74	1·89
November	1·80	3·07	1·59	1·66*	1·28	2·78	1·29	0·94	3·03	2·09
December	2·05	2·26	0·47	1·36*	4·76	2·29	2·65	2·15	2·50	1·73
Total	20·49	22·34	26·30	17·32	18·56	26·63	17·88	20·99	29·12	20·14

	1711*	1712*	1713†	1714†	1715	1716	1717‡	1718‡	1719‡	1720‡
January	2·30	2·32	4·18	0·38	0·95	1·89	0·90	1·80	0·80	0·40
February	1·66	1·67	3·98	1·15	0·68	0·38	1·40	0·90	1·50	2·70
March	1·58	1·59	0·69	1·31	2·75	0·43	2·60	1·80	1·80	1·90
April	1·97	1·98	1·68	1·24	2·89	1·10	1·90	1·90	1·10	1·90
May	1·97	1·98	2·08	0·61	1·03	2·08	1·30	1·60	1·20	2·20
June	1·86	1·88	2·79	1·08	3·58	1·81	1·60	1·80	1·90	1·70
July	2·63	2·66	3·94	1·39	4·38	0·98	2·00	1·20	0·90	4·00
August	2·41	2·42	1·40	1·24	4·48	0·46	2·10	0·60	2·90	2·40
September	2·15	2·16	0·56	1·24	2·01	2·16	2·00	1·60	1·00	1·90
October	2·43	2·45	1·68	1·01	3·09	3·46	2·00	2·70	1·70	3·00
November	2·69	2·70	1·40	0·77	1·88	0·97	4·00	3·70	2·00	2·00
December	2·23	2·24	1·52	0·85	0·56	1·57	1·10	3·00	0·90	1·70
Total	25·88	26·05	25·40	12·27	28·28	17·29	22·90	22·60	17·70	25·80

	1721‡	1722‡	1723‡	1724‡	1725	1726	1927	1728	1729	1730
January	1·50	0·60	1·10	3·00	0·65	3·92	2·41	3·09	0·74	0·45
February	0·90	0·80	1·80	1·00	0·10	0·64	2·06	0·63	0·79	1·23
March	1·00	2·00	0·50	1·80	0·38	1·46	2·10	2·49	1·13	3·59
April	3·00	1·00	1·00	1·00	1·97	0·68	0·53	3·47	1·60	0·67
May	1·30	1·80	0·80	1·20	2·76	1·78	3·84	1·62	1·51	1·75
June	2·80	1·40	1·00	2·00	4·05	3·39	2·85	4·61	1·20	3·75
July	1·70	4·00	3·00	3·00	0·75	4·19	0·80	4·61	1·04	2·39
August	1·60	2·30	0·30	2·20	2·70	0·08	0·07	1·67	3·04	0·02
September	2·80	0·40	0·80	1·90	2·66	4·95	1·75	1·68	3·51	2·10
October	2·50	1·80	1·30	1·20	1·23	0·98	1·72	2·29	1·42	2·46
November	3·50	1·80	1·20	1·30	1·17	1·31	0·40	2·16	2·43	1·57
December	1·10	0·90	1·80	1·40	1·65	3·61	2·57	1·00	1·95	1·50
Total	23·70	18·80	14·60	21·00	20·07	26·99	21·10	29·32	20·36	21·48

Appendix I — *continued*

	1731	1732	1733	1734	1735	1736	1737	1738	1739	1740
January	0·13	0·53	0·69	1·01	2·36	3·54	0·57	1·86	3·76	0·26
February	0·82	1·90	1·16	1·93	1·78	2·58	2·84	0·96	2·84	0·42
March	0·05	1·15	2·15	1·79	2·24	2·07	3·08	2·76	1·54	1·02
April	1·26	2·77	1·70	0·45	1·16	0·67	1·01	1·71	3·05	2·15
May	0·39	3·20	0·55	4·17	2·04	1·38	1·63	1·61	2·45	1·45
June	2·30	1·05	2·65	3·21	2·08	2·72	1·57	3·75	0·92	1·07
July	2·09	1·13	1·54	1·11	3·14	1·30	0·93	0·74	2·45	1·37
August	1·73	1·50	3·23	1·76	1·49	1·90	5·22	2·01	2·42	3·15
September	0·55	1·14	1·37	1·00	1·56	1·44	4·57	3·16	3·78	1·52
October	1·36	2·39	0·91	2·10	0·98	3·14	2·88	4·48	1·24	0·99
November	1·53	1·20	0·52	1·77	2·69	0·95	0·86	2·01	4·08	3·27
December	1·40	1·71	2·44	4·27	1·50	3·48	1·40	1·56	2·20	4·15
Total	13·61	19·67	18·91	24·57	23·02	25·17	26·56	26·61	30·73	20·82

	1741	1742	1743	1744	1745	1746	1747	1748	1749	1750
January	1·02	2·51	0·81	0·51	0·58	2·48	2·47	0·56	5·38	2·54
February	1·17	1·31	0·78	1·60	0·54	2·38	2·42	1·07	1·30	2·31
March	0·56	0·10	1·82	1·55	2·82	1·93	1·17	2·49	1·75	1·05
April	0·60	1·54	2·15	4·40	2·42	1·41	1·13	2·51	1·44	2·72
May	2·54	1·50	1·04	0·53	1·06	1·67	0·60	0·91	1·09	1·39
June	1·79	2·08	0·89	1·71	4·21	3·72	3·60	2·25	1·48	1·19
July	1·96	1·96	2·82	0·94	1·35	1·86	1·30	0·92	1·09	2·04
August	0·81	0·10	1·69	2·02	2·81	0·81	0·35	1·74	0·80	0·85
September	2·94	2·43	0·13	3·42	1·17	1·68	2·48	1·04	2·21	1·77
October	3·13	2·09	1·82	6·69	3·14	1·71	0·74	1·51	2·32	2·07
November	2·24	2·79	1·14	1·67	2·69	1·60	1·84	0·59	0·27	3·34
December	0·84	0·67	1·63	0·53	2·29	1·86	6·67	4·56	1·71	2·84
Total	19·60	19·08	16·72	25·57	25·08	23·11	24·77	20·15	20·84	24·11

	1751	1752	1753	1754	1755	1756	1757	1758	1759	1760
January	2·93	1·95	2·19	2·30	1·12	2·21	2·79	1·76	1·45	2·19
February	1·40	2·01	1·89	1·49	0·69	1·87	0·91	2·30	0·69	2·90
March	3·45	1·23	1·30	2·04	1·30	2·53	1·64	1·58	2·36	0·56
April	2·15	0·99	2·30	1·07	2·71	3·84	2·69	1·09	1·60	0·26
May	2·33	1·79	1·51	1·19	1·87	0·49	1·21	1·22	1·11	1·19
June	1·66	2·19	0·81	2·09	1·80	2·42	0·25	1·90	2·92	2·51
July	3·71	2·35	1·41	1·45	2·20	2·11	1·78	5·11	0·98	1·99
August	1·53	1·52	2·55	2·81	3·07	3·85	3·54	3·35	1·72	2·29
September	2·64	1·26	0·60	0·07	2·00	1·20	1·23	1·18	1·32	2·89
October	1·65	0·37	1·20	2·23	1·58	3·12	1·49	1·44	2·67	3·21
November	4·08	1·24	2·44	2·66	7·44	1·31	2·14	2·29	1·16	1·47
December	2·08	2·51	2·35	4·32	3·14	1·93	2·11	1·60	1·95	1·95
Total	29·61	19·41	20·55	23·72	28·92	26·88	21·78	24·82	19·93	23·41

	1761	1762	1763	1764	1765	1766	1767	1768	1769	1770
January	0·32	2·46	0·29	4·63	2·26	0·12	2·09	1·67	1·70	0·96
February	1·52	1·30	4·74	1·95	1·72	2·27	2·69	2·14	1·71	1·13
March	0·70	2·05	1·38	0·98	3·34	2·31	1·83	0·10	0·84	1·50
April	0·70	0·27	1·16	1·74	2·13	1·32	1·41	3·16	1·41	2·14
May	3·10	0·49	0·98	1·40	1·26	3·26	2·68	1·05	2·09	1·49
June	2·58	1·66	1·27	1·19	0·93	2·79	2·27	4·57	3·35	4·05
July	0·66	0·83	3·06	2·75	0·48	5·27	3·81	2·55	1·81	1·69
August	3·27	3·35	2·16	3·29	1·90	0·86	3·22	3·71	2·21	0·94
September	2·82	1·86	2·30	1·30	1·11	0·44	1·67	5·33	4·70	2·51
October	2·64	5·54	1·61	1·62	4·34	2·23	2·15	3·06	1·17	2·24
November	1·92	1·68	2·90	1·75	2·06	0·99	1·32	2·29	1·54	4·69
December	2·45	0·11	3·98	2·39	0·87	1·63	0·50	2·20	1·94	3·30
Total	22·68	21·60	25·83	24·99	22·40	23·49	25·64	31·83	24·47	26·64

	1771	1772	1773	1774	1775	1776	1777	1778	1779	1780
January	1·79	3·23	1·36	2·72	1·85	2·27+	0·97	2·31	0·25	0·77
February	0·81	3·11	1·42	2·68	2·36	2·27+	1·54	0·70	0·28	0·80
March	0·92	1·90	0·23	2·31	2·12	1·49	1·39	1·43	0·52	1·41
April	0·99	1·91	1·40	1·05	0·88	0·34	1·07	0·83	1·34	2·64
May	1·31	1·51	3·63	2·20	1·04	1·64	5·54	1·17	2·18	1·00
June	2·55	0·67	2·85	1·31	1·36	1·85	3·23	1·38	2·71	0·99
July	1·47	0·73	1·27	2·16	4·86	2·12	3·23	4·81	6·50	1·28
August	4·21	1·94	3·96	3·23	1·11	2·46	0·97	0·14	1·25	0·63
September	1·21	2·39	2·73	3·75	5·49	3·13	0·74	0·75	2·68	3·15
October	3·06	2·36	1·85	1·18	2·34	0·71	3·25	2·77	2·98	3·50
November	0·76	2·75	4·30	1·82	2·57	1·76	1·11	3·70	3·12	2·57
December	2·55	1·05	1·83	1·85	0·71	1·53	0·79	3·00	5·32	0·39
Total	21·63	23·55	26·83	26·26	26·69	22·57	23·83	22·99	29·13	19·13

	1781	1782	1783	1784	1785	1786	1787	1788	1789	1790
January	1·95	2·67	1·51	2·54	1·78	2·48	0·60	0·68	2·41	1·49
February	1·93	0·55	2·98	1·49	1·20	1·08	1·68	2·09	2·51	0·20
March	0·08	2·70	0·93	2·63	0·35	1·11	1·62	0·64	2·32	0·24
April	0·45	2·28	0·59	2·56	0·34	1·22	0·93	0·47	1·24	2·54
May	0·72	4·13	2·36	1·36	0·81	0·97	1·60	0·81	2·80	3·70
June	1·16	0·79	4·00	3·45	2·04	2·24	0·68	1·94	3·66	0·64
July	1·08	6·87	0·78	2·26	1·73	0·86	4·12	1·84	2·77	2·42
August	3·16	4·43+	2·23	2·84	3·05	1·19	0·60	4·30	1·91	2·26
September	1·95	2·28+	4·30	1·65	2·75	2·74+	0·78	3·81	1·87	0·52
October	0·32	2·16+	0·72	0·83	2·02+	2·74+	2·41	0·08	3·54	1·72
November	3·44	1·03	1·63	2·80+	2·02+	2·74+	1·51	0·62	1·24	3·40
December	1·54	0·94	1·22	2·80+	1·53	3·06	3·87	0·00	1·51	3·18
Total	17·78	30·83	23·25	27·21	19·62	22·43	20·40	17·28	27·78	22·31

Appendix I — *continued*

	1791	1792	1793	1794	1795	1796	1797	1798	1799	1800
January	2·91	2·29	1·99	0·51	0·61	2·70	1·22	1·41	1·20	3·11
February	2·29	0·90	2·00	0·82	1·58	1·44	0·28	0·87	2·83	0·33
March	0·92	2·27	1·47	1·37	2·20	0·09	0·99	0·42	0·54	0·39
April	1·57	1·96	1·38	1·77	0·63	0·38	2·35	0·66	2·11	3·66
May	0·76	2·05	1·10	2·80	0·35	2·91	1·82	2·05	2·21	1·38
June	0·60	2·05	0·54	0·49	4·23	0·68	5·34	1·21	0·70	1·27
July	2·67	2·91	2·05	0·65	1·77	2·41	1·63	3·65	3·68	0·00
August	1·26	2·62	1·66	2·04	2·35	0·67	3·53	1·94	2·80	1·86
September	0·27	2·42	3·10	3·81	0·10	1·95	5·14	3·09	3·57	3·43
October	2·33	2·38	1·44	3·59	3·22	2·28	2·53	4·34	2·77	1·63
November	3·44	0·57	2·66	4·23	3·08	1·53	1·86	3·87	2·01	4·81
December	1·44	2·24	2·29	1·29	1·23	1·66	2·04	1·09	0·44	2·11
Total	20·46	24·66	21·68	23·37	21·35	18·70	28·73	24·60	24·86	23·98

	1801	1802	1803	1804	1805	1806	1807	1808	1809	1810
January	1·56	0·19	1·95	2·11	1·91	2·33	0·62	1·34	4·09	0·26
February	0·68	1·90	0·94	1·70	1·33	0·67	1·41	0·90	2·03	1·44
March	1·41	0·51	0·57	1·95	1·11	1·68	0·24	0·21	0·92	2·54
April	0·48	1·25	1·38	2·03	2·00	0·32	0·57	2·09	3·76	1·70
May	1·91	1·52	2·14	1·58	1·08	1·29	3·63	1·42	1·03	1·04
June	1·00	2·35	4·25	0·66	4·19	0·65	1·71	0·81	1·41	0·56
July	4·46	3·57	1·73	4·70	2·75	6·19	0·42	3·11	3·49	3·78
August	1·99	0·66	0·95	3·54	4·47	2·65	2·23	1·53	1·81	2·46
September	1·59	0·85	1·16	0·00	1·94	2·43	2·45	4·78	3·16	1·98
October	1·86	2·08	0·59	2·59	1·75	1·00	0·97	4·05	0·18	1·92
November	4·16	1·28	3·09	5·05	1·00	3·23	3·10	2·21	1·38	6·08
December	3·19	1·52	3·91	0·65	2·28	3·44	0·61	0·92	2·95	2·94
Total	24·29	17·68	22·66	26·56	25·81	25·88	17·96	23·37	26·21	26·70

	1811	1812	1813	1814	1815	1816	1817	1818	1819	1820
January	1·08	1·54	0·40	1·68	0·9	2·1	3·2	1·9	2·3	1·9
February	1·26	3·70	2·42	0·79	1·3	1·6	1·3	2·0	3·0	0·6
March	0·80	2·42	0·62	1·08	2·2	1·9	2·1	3·8	1·8	1·5
April	1·12	1·34	1·44	1·95	2·7	2·1	0·1	3·3	3·1	1·6
May	2·58	2·34	3·16	2·67	2·3	2·2	4·6	2·7	3·3	4·0
June	1·82	2·54	1·12	2·34	1·9	2·4	1·4	0·7	2·5	2·3
July	3·22	2·46	2·82	1·02	1·8	4·3	4·3	0·8	2·2	4·8
August	2·26	1·92	0·88	3·01	1·8	2·5	2·7	0·1	0·4	1·9
September	1·54	0·64	1·04	1·45	1·2	2·1	0·9	4·2	3·4	2·4
October	2·52	3·86	4·74	2·41	2·6	2·8	2·6	2·1	2·3	2·9
November	2·42	2·34	1·10	2·70	1·5	3·0	2·0	2·7	3·0	2·0
December	2·04	0·70	0·72	3·38	2·3	3·1	3·8	1·4	3·8	1·8
Total	22·66	25·80	20·46	24·48	22·5	30·1	29·0	25·7	31·1	27·7

	1821	1822	1823	1824	1825	1826	1827	1828	1829	1830
January	2·4	0·6	1·5	1·0	1·1	0·3	1·2	4·3	0·4	1·7
February	0·0	1·1	3·5	2·5	1·0	1·9	0·7	1·1	1·3	2·5
March	3·9	1·5	1·5	1·9	1·4	1·9	2·6	1·0	0·7	0·3
April	2·0	2·9	2·0	2·1	2·0	1·1	1·3	2·4	4·8	3·2
May	2·4	2·1	0·8	4·2	3·3	2·7	2·6	1·7	0·6	2·2
June	2·4	0·9	1·2	3·8	0·8	1·1	0·7	2·2	1·7	2·6
July	3·1	4·5	3·6	2·0	0·1	2·6	1·4	7·0	4·2	1·9
August	2·1	2·0	3·0	4·4	2·7	1·9	1·2	4·2	4·5	3·9
September	3·7	1·5	1·0	3·5	2·8	3·4	3·9	2·6	3·6	3·5
October	2·6	4·0	4·4	2·6	3·0	1·9	4·4	1·5	1·9	0·8
November	4·7	4·1	1·8	4·3	3·2	2·8	1·3	1·0	1·4	3·4
December	5·2	2·5	2·8	4·0	3·2	1·4	3·6	2·5	0·1	1·2
Total	34·5	27·7	27·1	36·3	24·6	23·0	24·9	31·5	25·2	27·2

	1831	1832	1833	1834	1835	1836	1837	1838	1839	1840
January	1·1	1·3	1·1	3·2	0·7	1·9	2·6	0·9	1·2	2·16
February	3·0	1·6	3·6	0·4	2·6	1·8	1·7	2·0	1·5	1·09
March	2·2	1·4	1·0	0·7	2·5	2·2	0·5	1·0	1·8	0·25
April	3·4	0·4	1·2	0·5	1·2	2·7	1·3	0·5	1·5	0·09
May	1·7	1·5	0·2	1·0	3·0	1·3	1·0	1·5	1·6	1·87
June	2·1	3·3	2·2	1·5	2·4	1·1	1·0	5·1	1·9	1·37
July	3·4	0·7	1·6	5·3	0·3	1·9	1·5	2·0	3·7	1·50
August	2·0	3·4	1·8	3·3	1·2	2·6	4·6	0·9	2·7	0·99
September	2·2	0·4	1·9	0·9	4·2	3·2	1·2	2·9	5·0	2·60
October	5·5	2·5	1·3	0·4	4·2	4·2	2·5	2·0	1·9	1·48
November	2·1	1·6	2·3	1·3	2·2	2·4	1·7	3·2	4·4	2·62
December	2·1	1·2	4·8	1·1	0·4	1·8	1·4	1·8	2·4	0·41
Total	30·8	19·3	23·0	19·6	24·9	27·1	21·0	23·8	29·6	16·43

	1841	1842	1843	1844	1845	1846	1847	1848	1849	1850
January	2·11	1·02	1·35	2·42	2·40	2·82	1·38	1·20	1·50	1·20
February	1·32	1·05	2·39	2·32	0·93	1·47	1·39	2·60	2·30	1·40
March	1·35	1·90	0·51	2·30	1·51	0·88	0·77	3·10	0·60	0·40
April	1·92	0·43	1·72	0·35	0·55	3·05	0·99	3·44	1·98	2·25
May	2·06	2·09	3·75	0·30	2·21	1·50	1·40	0·40	3·70	2·30
June	2·70	0·95	1·30	1·56	1·89	0·50	1·50	3·50	0·30	1·00
July	3·60	2·96	2·42	2·18	1·85	1·50	0·67	1·98	2·90	2·82
August	2·20	1·78	3·62	1·71	3·10	4·00	1·95	4·25	0·45	1·70
September	3·95	3·99	0·46	1·19	2·12	1·79	1·56	2·38	3·25	1·35
October	5·95	1·41	4·25	4·01	1·38	5·13	2·00	3·50	2·70	1·58
November	3·70	4·25	2·30	4·50	2·40	1·52	2·00	1·20	1·50	2·18
December	2·40	0·74	0·40	0·36	2·00	1·13	2·00	2·55	2·40	1·35
Total	33·26	22·57	24·47	23·20	22·34	25·29	17·61	30·10	23·58	19·53

Appendix I — *continued*

	1851	1852	1853	1854	1855	1856	1857	1858	1859	1860
January	2·70	3·60	2·11	1·40	1·47	2·63	2·60	0·75	0·80	1·81
February	1·25	0·90	1·48	1·21	1·00	1·10	0·20	1·70	0·86	1·10
March	4·05	0·17	1·50	0·32	1·98	1·10	0·83	0·80	1·35	1·86
April	2·30	0·49	3·21	0·59	0·09	2·28	1·40	2·25	2·17	1·00
May	0·80	1·90	1·50	3·51	1·80	3·45	0·33	2·00	2·35	3·90
June	1·75	4·60	2·75	0·91	0·85	1·60	2·70	1·20	1·40	5·80
July	4·20	2·25	5·48	1·75	5·25	0·90	1·10	3·00	3·30	2·80
August	2·60	4·35	2·75	2·61	1·40	2·42	2·50	1·50	1·13	3·68
September	0·50	3·80	2·23	0·98	1·95	2·80	3·40	0·86	3·80	3·10
October	2·18	3·75	4·23	2·42	5·20	1·91	4·20	1·44	3·60	1·60
November	0·65	6·00	1·95	1·90	1·50	1·25	1·35	0·50	2·90	2·50
December	0·55	2·20	0·80	1·41	1·10	1·83	0·55	1·70	2·17	2·75
Total	23·53	34·01	29·99	19·01	23·59	23·27	21·16	17·70	25·83	31·90

	1861	1862	1863	1864	1865	1866	1867	1868	1869	1870
January	0·55	1·79	2·71	0·88	3·32	3·68	2·80	3·69	2·92	1·49
February	1·80	0·46	0·50	0·76	1·75	4·03	1·21	1·20	2·34	0·54
March	2·15	3·54	0·70	2·53	0·85	1·63	2·30	1·00	1·41	2·05
April	0·83	2·82	0·45	0·82	0·40	2·44	2·10	1·76	1·01	0·28
May	1·79	2·84	1·25	2·00	4·37	1·94	2·20	1·34	3·43	0·47
June	1·90	1·93	3·91	0·92	2·45	3·64	1·51	0·30	1·15	0·39
July	2·20	1·66	0·88	0·27	2·27	1·62	5·30	0·71	0·55	2·01
August	0·57	3·01	1·82	1·31	3·97	2·42	2·50	2·31	1·21	2·02
September	1·46	1·61	2·95	2·76	0·16	3·90	2·61	1·37	3·08	1·63
October	0·88	4·07	1·82	1·06	5·90	2·09	1·93	2·35	1·77	3·34
November	5·07	1·00	1·59	2·57	2·39	1·48	0·42	1·05	2·38	1·20
December	1·25	1·59	1·08	0·50	0·87	1·85	1·70	4·70	2·77	3·13
Total	20·45	26·32	19·66	16·38	28·70	30·72	26·58	21·78	24·02	18·55

	1871	1872	1873	1874	1875	1876	1877	1878	1879	1880
January	1·76	3·45	2·17	0·98	3·43	0·82	5·02	1·19	2·71	0·44
February	0·97	0·79	1·55	1·11	0·93	1·76	1·75	1·11	4·11	2·19
March	0·99	1·74	1·35	0·43	0·61	2·76	2·20	1·12	0·97	0·69
April	2·83	1·59	0·39	1·27	1·61	2·05	2·70	3·87	3·05	2·01
May	0·81	2·85	1·35	0·60	1·47	0·78	1·75	4·10	3·93	0·29
June	3·20	1·42	2·99	2·54	2·31	1·47	1·63	2·75	3·79	2·13
July	3·31	2·00	2·07	1·26	5·11	0·90	3·21	2·35	4·37	4·84
August	0·96	1·58	2·06	1·29	0·65	1·93	2·83	6·52	5·05	0·69
September	3·91	1·37	2·35	2·80	1·99	2·45	0·70	0·98	2·63	4·43
October	1·31	4·36	2·86	3·73	3·83	1·50	1·99	2·10	0·97	5·95
November	0·49	2·81	1·93	2·17	2·93	2·65	3·43	2·45	0·77	1·79
December	1·10	3·74	0·40	1·51	0·94	5·77	1·35	1·30	0·76	3·29
Total	21·65	27·71	21·46	19·68	25·82	24·85	28·57	29·82	33·11	28·74

	1881	1882	1883	1884	1885	1886	1887	1888	1889	1890
January	1·16	1·28	2·33	2·11	1·38	3·45	1·47	0·86	0·91	2·16
February	2·55	1·32	3·33	1·58	3·01	0·65	0·56	0·90	2·07	0·91
March	1·98	1·23	1·02	1·23	1·47	1·44	1·53	3·06	1·36	1·53
April	0·77	2·59	1·61	1·26	1·78	1·50	1·08	2·21	2·23	1·73
May	1·13	1·31	1·83	0·63	2·90	3·91	1·63	1·13	3·05	1·41
June	1·62	2·03	1·17	2·19	1·85	1·03	1·21	2·35	1·28	3·31
July	1·93	2·21	2·03	2·23	0·47	2·39	0·82	4·43	3·05	4·53
August	4·77	1·13	0·91	0·71	1·09	0·69	2·67	2·97	2·17	1·95
September	2·21	2·36	3·27	1·93	4·33	1·78	2·17	1·44	1·57	0·59
October	2·41	5·79	1·76	1·11	3·86	2·09	1·45	1·33	3·90	1·03
November	2·36	2·35	2·51	1·65	2·95	3·07	3·05	3·88	0·81	1·53
December	2·65	1·98	0·69	2·26	1·16	3·47	1·37	1·39	1·20	0·55
Total	25·53	25·58	22·46	18·92	26·25	25·47	19·02	25·96	23·59	21·23

	1891	1892	1893	1894	1895	1896	1897	1898	1899	1900
January	1·61	0·45	1·31	2·93	1·43	0·59	1·74	0·85	2·39	2·93
February	0·09	1·39	2·60	1·57	0·13	0·27	2·35	1·33	2·02	3·17
March	1·32	1·05	0·42	1·21	1·23	2·88	3·58	1·17	0·56	0·93
April	0·99	1·07	0·10	1·47	1·63	0·58	1·39	1·03	2·37	0·93
May	2·53	1·47	1·40	1·57	0·33	0·19	0·95	2·45	1·47	0·99
June	1·59	2·79	0·86	2·20	0·33	1·63	2·73	1·39	1·35	2·10
July	2·95	2·07	1·81	4·37	4·50	1·29	0·93	0·67	0·87	1·25
August	4·03	3·28	1·60	2·52	2·87	1·58	2·63	1·11	0·45	2·65
September	1·03	3·04	1·10	1·37	1·53	5·36	1·95	0·42	2·11	1·04
October	5·93	3·77	4·11	3·89	2·99	2·39	0·57	3·34	2·03	1·61
November	1·92	2·71	1·83	2·98	3·42	1·09	0·90	2·06	3·98	1·71
December	2·91	1·17	2·34	1·99	1·97	3·11	2·14	2·41	1·25	2·55
Total	26·89	24·26	19·49	28·07	22·37	20·97	21·87	18·22	20·85	21·87

	1901	1902	1903	1904	1905	1906	1907	1908	1909	1910
January	0·85	0·73	2·19	2·37	1·08	3·36	0·68	1·82	0·74	1·68
February	0·89	0·85	0·99	2·24	0·67	1·69	1·15	1·20	0·31	2·76
March	2·02	1·75	2·35	1·28	3·18	1·03	0·89	2·41	2·73	0·96
April	2·11	0·49	1·76	0·94	1·53	0·44	3·14	2·31	1·76	1·06
May	0·45	2·45	3·35	2·65	0·75	1·80	1·68	1·33	1·60	1·84
June	1·29	3·71	7·21	1·10	4·06	2·84	2·81	1·95	3·41	2·66
July	2·09	1·13	4·27	2·03	1·69	1·03	1·80	2·44	2·68	2·49
August	1·87	3·45	3·93	1·66	2·80	0·77	1·79	2·43	1·31	2·79
September	1·52	2·52	3·23	1·69	1·75	1·75	0·53	1·41	2·49	0·45
October	1·89	1·39	5·49	1·63	1·22	3·18	3·65	2·17	3·60	2·17
November	0·47	1·57	1·79	1·74	3·10	3·88	2·08	0·68	0·70	3·11
December	3·24	1·38	1·61	1·86	0·74	1·85	3·61	2·08	2·33	3·53
Total	18·72	21·44	38·17	21·19	22·57	23·62	23·81	22·23	23·66	25·50

Photograph by R. K. Pilsbury

PLATE I—TREE DAMAGED BY LIGHTNING STRIKE AT BRACKNELL

See page 373.

PLATE II—TWO PINE TREES GROWING ABOVE THEIR SURROUNDINGS

(Photographed in 1965)

Photographs by R. K. Pilsbury

PLATE III—PINE TREES AFTER A LIGHTNING STRIKE IN AUGUST 1971

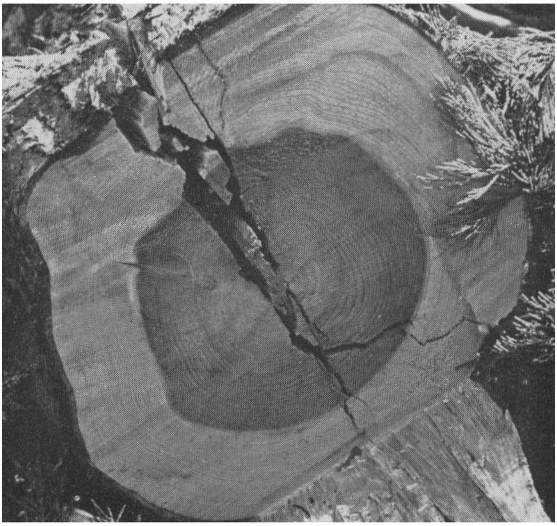
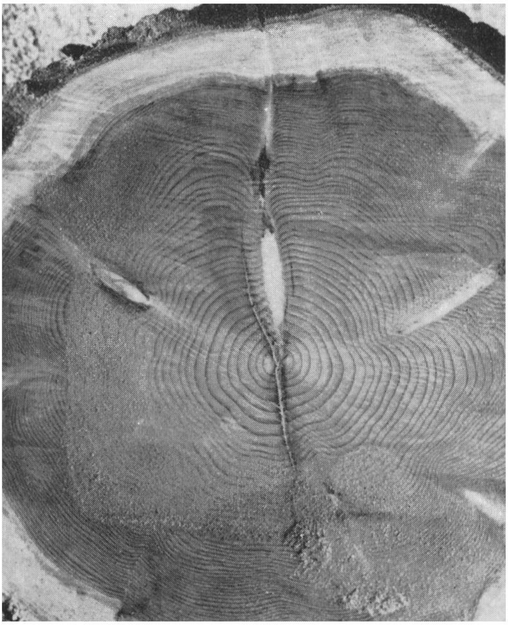


PLATE IV—CROSS-SECTION OF TRUNK AT ABOUT 70 ft



Photographs by R. K. Pilsbury

PLATE V—CROSS-SECTION OF TRUNK AT ABOUT 30 ft

At this point the split was restricted to the centre with some charring. From a count of tree rings the pine was 90–95 years old.

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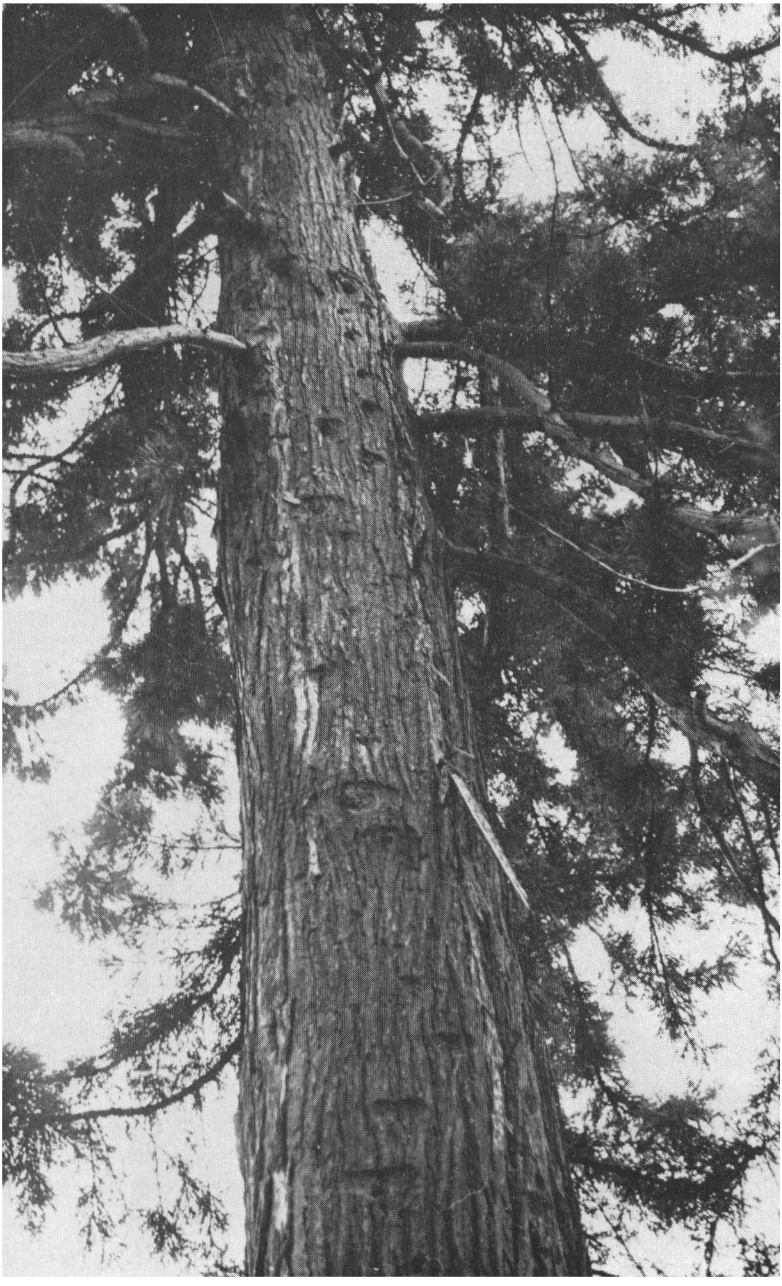

Photograph by R. K. Pilsbury

PLATE VI—BURN MARKS ON SMALLER TREE

There is a vertical burn mark on the right of the trunk with bark hanging loose. It seems that lightning jumped across from a thick branch of the damaged tree alongside.

Appendix I — *continued*

	1911	1912	1913	1914	1915	1916	1917	1918	1919	1920
January	1·19	3·46	2·56	0·55	4·19	1·22	1·13	2·94	3·53	2·17
February	1·31	1·35	0·78	2·43	3·31	3·09	0·79	0·84	2·21	0·41
March	1·31	2·72	2·09	3·94	0·80	3·95	1·74	0·90	3·06	1·17
April	1·88	0·15	2·57	0·87	1·26	1·02	2·15	3·16	2·34	2·67
May	1·55	1·29	1·77	1·75	3·16	1·66	2·04	1·82	0·36	1·51
June	1·98	3·19	0·43	2·29	0·58	2·16	3·71	1·16	1·18	3·07
July	0·83	1·68	1·91	1·93	4·21	1·39	4·50	4·78	2·65	4·40
August	0·81	5·29	1·24	1·76	3·25	3·92	4·18	1·40	2·11	1·49
September	1·36	2·14	1·89	1·00	2·33	1·62	2·06	5·71	1·45	2·45
October	3·00	2·28	3·38	1·19	1·93	3·67	3·41	1·13	0·57	1·68
November	3·40	1·67	2·26	2·98	2·37	3·91	1·32	2·10	1·05	1·32
December	4·45	2·69	0·98	6·56	5·39	2·25	1·18	2·11	3·74	1·94
Total	23·03	27·91	21·85	27·25	32·79	29·87	28·20	28·05	24·27	24·28

	1921	1922	1923	1924	1925	1926	1927	1928	1929	1930
January	2·04	2·23	1·29	2·51	1·76	2·33	1·91	3·10	0·73	2·71
February	0·19	1·87	2·81	0·41	3·20	2·28	3·40	1·40	0·51	0·58
March	1·33	1·69	2·07	0·85	0·44	0·19	2·19	1·73	0·03	1·48
April	1·06	2·60	1·57	3·39	1·98	2·66	1·78	1·41	1·07	1·87
May	0·98	1·02	2·06	2·42	1·91	1·73	1·09	1·76	1·27	3·47
June	0·20	0·98	0·25	3·45	0·04	3·39	2·53	2·24	0·88	1·31
July	0·15	3·30	3·26	3·75	3·93	1·72	3·00	2·06	2·59	1·84
August	0·99	2·07	1·57	2·50	2·58	0·58	4·07	2·59	2·16	2·82
September	1·76	1·56	1·38	2·95	2·50	1·47	4·49	1·03	0·16	2·53
October	0·44	0·75	5·33	3·63	3·07	2·04	1·27	3·63	2·73	1·07
November	1·70	1·42	1·47	2·28	1·48	5·12	2·69	1·81	4·83	3·85
December	1·30	2·83	2·05	2·84	2·67	0·24	3·71	2·35	4·43	1·82
Total	12·14	22·35	25·13	30·99	25·56	23·77	32·12	25·11	21·38	25·35

	1931	1932	1933	1934	1935	1936	1937	1938	1939	1940
January	1·07	1·61	1·34	1·20	0·89	3·91	3·76	2·23	4·31	2·47
February	1·47	0·17	2·65	0·22	2·30	1·61	4·05	0·31	0·80	1·60
March	0·32	1·29	2·17	2·12	0·37	0·90	2·76	0·26	1·00	3·39
April	3·66	2·23	0·66	1·47	2·69	1·68	1·98	0·09	2·21	1·61
May	2·48	4·03	1·83	0·44	1·39	0·51	2·15	1·30	1·39	1·21
June	1·66	0·26	1·93	1·00	3·37	3·53	1·81	0·35	1·15	1·21
July	2·91	2·45	1·74	3·19	1·63	2·35	0·95	1·02	1·79	2·69
August	4·85	1·17	0·50	1·77	1·99	0·48	2·98	2·70	3·43	0·09
September	2·09	2·32	2·72	1·26	2·55	2·81	2·03	1·94	0·91	1·37
October	0·65	5·00	1·44	0·87	1·98	1·79	2·37	2·05	4·91	2·41
November	2·14	1·01	0·94	1·76	4·35	2·79	1·38	2·60	4·43	6·76
December	0·54	0·46	0·32	4·42	2·15	1·38	3·44	3·29	0·84	1·12
Total	23·83	22·00	18·24	19·72	25·67	23·74	29·66	18·15	27·17	25·93

	1941	1942	1943	1944	1945	1946	1947	1948	1949	1950
January	2·46	2·19	4·73	1·55	1·66	1·39	1·35	3·57	1·20	0·87
February	1·93	0·88	1·44	0·67	1·39	2·26	1·19	1·43	0·88	3·16
March	3·21	1·66	0·34	0·09	0·80	1·17	4·66	0·58	0·92	0·65
April	1·72	0·81	0·73	1·31	1·13	1·91	1·68	1·24	1·47	2·44
May	1·87	3·00	1·88	0·69	2·41	3·47	1·35	2·22	2·30	1·72
June	1·93	1·42	1·28	1·51	1·76	2·78	3·17	1·67	0·50	1·85
July	4·06	1·74	1·45	1·67	2·69	3·11	1·41	1·19	1·12	3·15
August	5·89	2·21	1·40	1·97	1·26	3·74	0·40	2·87	1·50	2·33
September	0·35	1·04	2·25	2·23	1·68	3·47	1·17	1·24	0·35	2·45
October	0·76	3·43	2·52	2·71	2·08	1·33	0·15	1·83	5·24	0·57
November	2·53	1·98	1·31	3·42	0·29	4·06	1·07	1·59	2·16	4·11
December	1·56	2·19	1·39	1·19	2·69	1·95	2·14	2·02	1·47	1·58
Total	28·26	22·55	20·72	19·01	19·83	30·61	19·75	21·48	19·11	24·88

	1951	1952	1953	1954	1955	1956	1957	1958	1959	1960
January	3·04	1·82	0·85	0·92	1·92	3·69	1·44	1·91	2·13	1·76
February	4·98	0·80	1·15	1·95	1·16	0·21	3·00	2·29	0·09	1·66
March	2·87	2·73	0·43	1·93	0·91	0·77	1·02	1·02	1·57	1·60
April	2·30	1·18	2·22	0·38	0·32	0·95	0·34	1·28	2·04	0·52
May	2·02	2·37	1·55	1·78	3·72	0·22	1·05	2·28	0·53	1·65
June	0·94	1·72	1·83	4·00	2·18	1·85	0·97	4·13	0·60	1·21
July	1·00	0·53	3·61	2·34	0·40	5·93	3·28	2·48	1·57	3·37
August	3·35	3·50	1·73	3·14	0·71	3·68	3·84	3·41	1·13	1·81
September	2·11	2·58	2·00	1·59	1·77	2·01	2·49	3·96	0·10	3·43
October	0·83	2·69	2·29	1·72	2·37	2·12	1·84	2·04	1·87	5·21
November	5·29	3·50	1·48	3·70	0·91	0·39	2·29	1·89	2·36	3·79
December	1.45	2·36	0·50	1·95	1·77	2·56	1·73	2·97	3·07	1·98
Total	30·17	25·78	19·65	25·41	18·13	24·37	23·29	29·69	17·06	27·97

	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970
January	2·44	2·81	0·83	0·53	1·95	1·24	1·24	2·28	2·55	2·26
February	2·15	0·63	0·26	0·70	0·35	2·70	2·03	0·96	1·55	1·41
March	0·16	1·35	2·30	3·27	1·83	0·43	1·43	0·91	2·19	1·70
April	2·06	1·66	1·60	3·18	1·41	3·62	1·91	2·22	0·60	2·46
May	0·95	1·56	1·85	1·67	1·37	1·91	3·87	2·52	2·09	0·80
June	1·39	0·28	1·92	3·89	1·60	2·61	2·07	2·03	1·04	1·21
July	1·20	2·33	1·29	1·95	2·15	2·74	2·20	2·83	2·95	2·59
August	2·30	2·43	2·20	1·83	2·33	3·05	1·61	3·06	3·68	2·11
September	2·14	2·84	2·34	0·41	4·20	1·09	2·25	4·82	0·11	2·23
October	2·11	2·15	1·50	1·21	0·84	3·93	3·56	2·03	0·16	0·57
November	1·82	1·99	4·50	1·34	2·85	1·31	1·37	1·50	3·17	6·18
December	3·44	2·21	0·67	1·34	3·72	2·93	2·12	2·79	1·64	1·51
Total	22·16	22·23	21·26	21·32	24·60	27·56	25·66	27·95	21·74	25·03

Appendix II

Meteorological Office estimates of general annual rainfall over England and Wales, 1727–1970 (in inches). The estimates were prepared by averaging the annual totals measured at selected stations.

1727	34·5	1780	25·9	1833	36·9	1886	41·2	1939	39·9
1728	38·7	1781	29·0	1834	31·1	1887	26·1	1940	35·6
1729	35·8	1782	40·2	1835	33·9	1888	34·5	1941	33·8
1730	28·9	1783	33·2	1836	39·7	1889	33·0	1942	33·1
1731	22·9	1784	31·5	1837	31·0	1890	31·7	1943	32·8
1732	32·3	1785	30·1	1838	31·4	1891	39·1	1944	35·3
1733	29·3	1786	34·3	1839	40·3	1892	33·1	1945	32·8
1734	40·9	1787	36·8	1840	30·8	1893	29·2	1946	41·6
1735	34·8	1788	23·0	1841	44·2	1894	38·0	1947	32·4
1736	38·7	1789	40·6	1842	33·1	1895	33·8	1948	37·5
1737	33·5	1790	32·7	1843	37·0	1896	32·8	1949	30·9
1738	26·0	1791	37·3	1844	30·5	1897	35·6	1950	40·2
1739	34·5	1792	42·0	1845	34·0	1898	30·6	1951	43·7
1740	28·5	1793	30·7	1846	36·9	1899	33·1	1952	35·5
1741	23·9	1794	35·5	1847	33·6	1900	38·4	1953	29·8
1742	28·0	1795	32·7	1848	44·5	1901	31·1	1954	42·7
1743	24·8	1796	30·3	1849	33·3	1902	29·6	1955	30·9
1744	34·2	1797	38·3	1850	31·4	1903	45·1	1956	34·2
1745	35·7	1798	31·4	1851	30·4	1904	31·4	1957	35·4
1746	31·5	1799	36·8	1852	49·8	1905	30·3	1958	40·5
1747	36·0	1800	32·8	1853	34·4	1906	35·6	1959	31·7
1748	29·7	1801	34·8	1854	27·0	1907	34·9	1960	46·1
1749	30·5	1802	31·2	1855	31·1	1908	32·0	1961	34·4
1750	26·0	1803	29·8	1856	31·9	1909	37·0	1962	31·1
1751	39·1	1804	33·5	1857	33·4	1910	39·8	1963	33·5
1752	32·1	1805	29·1	1858	27·7	1911	33·1	1964	27·8
1753	36·7	1806	37·2	1859	35·4	1912	44·0	1965	39·1
1754	31·6	1807	30·6	1860	42·1	1913	34·5	1966	40·3
1755	33·6	1808	31·9	1861	31·9	1914	38·1	1967	38·7
1756	34·6	1809	33·5	1862	36·4	1915	38·8	1968	38·6
1757	34·5	1810	36·1	1863	32·1	1916	40·1	1969	35·8
1758	34·4	1811	33·5	1864	26·9	1917	34·5	1970	35·9
1759	30·7	1812	35·0	1865	39·0	1918	37·7		
1760	35·7	1813	31·4	1866	39·0	1919	37·0		
1761	33·5	1814	35·6	1867	33·8	1920	38·4		
1762	31·9	1815	33·7	1868	35·7	1921	24·7		
1763	43·0	1816	37·3	1869	35·7	1922	37·1		
1764	37·4	1817	36·0	1870	28·9	1923	39·8		
1765	31·0	1818	34·2	1871	34·0	1924	42·3		
1766	28·8	1819	35·2	1872	50·7	1925	37·3		
1767	34·0	1820	31·2	1873	31·3	1926	35·9		
1768	46·9	1821	39·6	1874	33·3	1927	43·3		
1769	31·0	1822	34·6	1875	40·3	1928	40·4		
1770	37·7	1823	40·2	1876	41·2	1929	35·2		
1771	28·9	1824	41·6	1877	44·6	1930	41·4		
1772	37·9	1825	33·7	1878	38·8	1931	38·4		
1773	38·6	1826	29·0	1879	38·4	1932	36·3		
1774	35·3	1827	36·9	1880	39·7	1933	28·6		
1775	39·2	1828	40·3	1881	38·4	1934	33·5		
1776	33·8	1829	34·1	1882	44·7	1935	39·8		
1777	33·3	1830	36·7	1883	37·7	1936	38·4		
1778	37·0	1831	40·2	1884	31·0	1937	38·8		
1779	33·2	1832	35·2	1885	35·6	1938	34·9		

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THE STRATOSPHERIC WINTER ANOMALY—A REVIEW OF ROCKETSONDE OBSERVATIONS AT SOUTH UIST (1967–71)

By G. C. BRIDGE

Summary. The British Meteorological Office has been making soundings of the stratosphere over the four winter periods between 1967 and 1971 using the SKUA rocketsonde from a height of 20 km up to 65 km, from South Uist in the Outer Hebrides. Height–time profiles of temperature and zonal wind were drawn from the rocketsonde observations and show clearly the large fluctuations which occurred at this time of year. Warming events occurred towards the end of December each year, with temperature increases over three or four days in excess of 30 degC at 45 km. Complete disruption of flow occurred simultaneously with the warming in three of the four winters investigated. Return to more normal profiles of temperature and wind was achieved by the end of February. Means and standard deviations of temperatures and zonal winds have been calculated together with a comparison with the COSPAR International Reference Atmosphere, 1965, for 60°N.

Vertical motion is considered the prime mechanism for such temperature increases, being produced by developing systems in the northern hemispherical flow which itself adopts an unstable wave number two characteristic at this time of year. External triggering from the troposphere, mesosphere, or by bursts of solar radiation is considered a possible method of initiating the development of such systems.

Introduction. The High Atmosphere Branch of the Meteorological Office has been making regular soundings of the winter stratosphere using the rocketsonde technique, from a height of 65 km down to 20 km, over the past four years, from the Royal Artillery Range at West Geirinish, on the island of South Uist in the Outer Hebrides. These soundings have been made using the SKUA sounding rocket system, which is briefly described, and the information on temperatures and winds so received, is used in preparing height–time profiles. Coded versions of available soundings appear as ROCOB data in the *Daily Aerological Report** and, if used in conjunction with similar data from other locations in the northern hemisphere, chiefly the U.S.A. and Canada, circulation patterns and temperature fields for the stratosphere over the northern hemisphere during the winter months can be constructed.

The SKUA rocket system. The SKUA is a solid-propellant end-burning type of rocket about 2·5 m in length with a detachable booster motor 1 m long. The main motor burns for approximately 33 seconds taking the rocket to around 25 km, then coasts to an apogee of 65 to 85 km depending on the launcher setting and the type of SKUA. At apogee a small charge forces off the nose cone, liberating the sonde and a parachute of 5-m diameter. The latter has metallized panels allowing it to be tracked by radar and hence used as a wind-finding sensor. The sonde, which is essentially a sensitive resistance thermometer with supporting telemetry, transmits in the 27 to 28-MHz range, the signal being detected by standard radiosonde receiving equipment, yielding a graph of temperature against time. Certain corrections[1] have to be applied, chiefly for dynamic and solar radiation heating of the temperature element. Firing at night eliminates the correction for solar radiation heating, the magnitude of which is uncertain because of variations in solar elevation, shadowing effects of the element ring and the periodic swing of the parachute and sonde.

* London, Meteorological Office. *Daily Aerological Report.*

The stratospheric circulation. Before presenting the results of the observations from the last four winter campaigns, a brief description of the typical annual stratospheric circulation will help to set the picture.

A large-scale anticyclonic circulation generally concentric with the north pole persists during the summer months throughout the stratosphere, with weakest flow at the equator. Temperature fields at this time of year are also rather weak and likewise tend to be concentric with the pole. Cooling by radiation loss near the pole, which occurs from August onwards, gradually breaks down the anticyclonic flow, so that by the end of the month and at high altitudes, westerlies have become established. These slowly descend through the remainder of the stratosphere, with velocities at all levels increasing to a maximum value by December. These velocities can range from around 25 m/s at 20 km to 150 m/s at 50 km in U.K. latitudes, but fall off rapidly south of about 30°N. A high cell normally appears to the south of the Aleutian Islands tending to elongate and displace the polar vortex towards Eurasia. The high is accompanied by a warming through a deep layer of the stratosphere from eastern Siberia to Alaska. At high altitudes however, the flow usually takes the form of a warm ridge situated several hundreds of kilometres to the west, giving the axis of warming a marked westward tilt in the vertical plane. Warming by descent in the right-hand exit of the westerly jet formed over eastern Siberia and northern Japan is regarded as a possible mechanism for maintaining the Aleutian warm region for most of the winter months. During the middle winter period when westerly flow is at a maximum, disturbances producing sudden warmings, frequently accompanied by disruption of flow, occur in the vicinity of western Europe.

Towards the end of March the pole, which is now receiving solar radiation once again, becomes noticeably warmer, the westerly flow at high latitudes decreases and eventually reverts to anticyclonic flow and this change slowly spreads south to affect most of the northern hemisphere by May.

In the absence of dynamical effects, the temperature structure in the stratosphere is largely the result of a delicate balance between molecular and monatomic oxygen and ozone. Ultra-violet radiation at wavelengths of around 2500 Å is strongly absorbed by ozone converting it to molecular and monatomic oxygen. The ozone mixing ratio increases with height from the tropopause to around 35 km, above which photochemical equilibrium is maintained, largely controlling the temperature at any height, and responsible for the maximum value (approximately 0°C in U.K. latitudes) prevailing at around 50 km, commonly called the stratopause.

Analysis of results. The diagrams in Figure 1 are height–time cross-sections for West Geirinish, over the winter months of the past four years. They are constructed from ROCOB data, the respective dates being marked by a black dot, but over periods of meagre observations, shown by broken lines, trends have been assessed by reference to 50, 30, or 10-mb charts as published by the Free University of Berlin.

Marked variability of stratospheric temperatures over the winter months becomes very obvious. At the start of each cross-section, temperatures of around 0°C frequently occurred in the 50 to 55-km region, as discussed earlier, with a steady decrease in temperature to a minimum of −70°C or lower at around 30 km. The height of maximum temperature appeared to descend

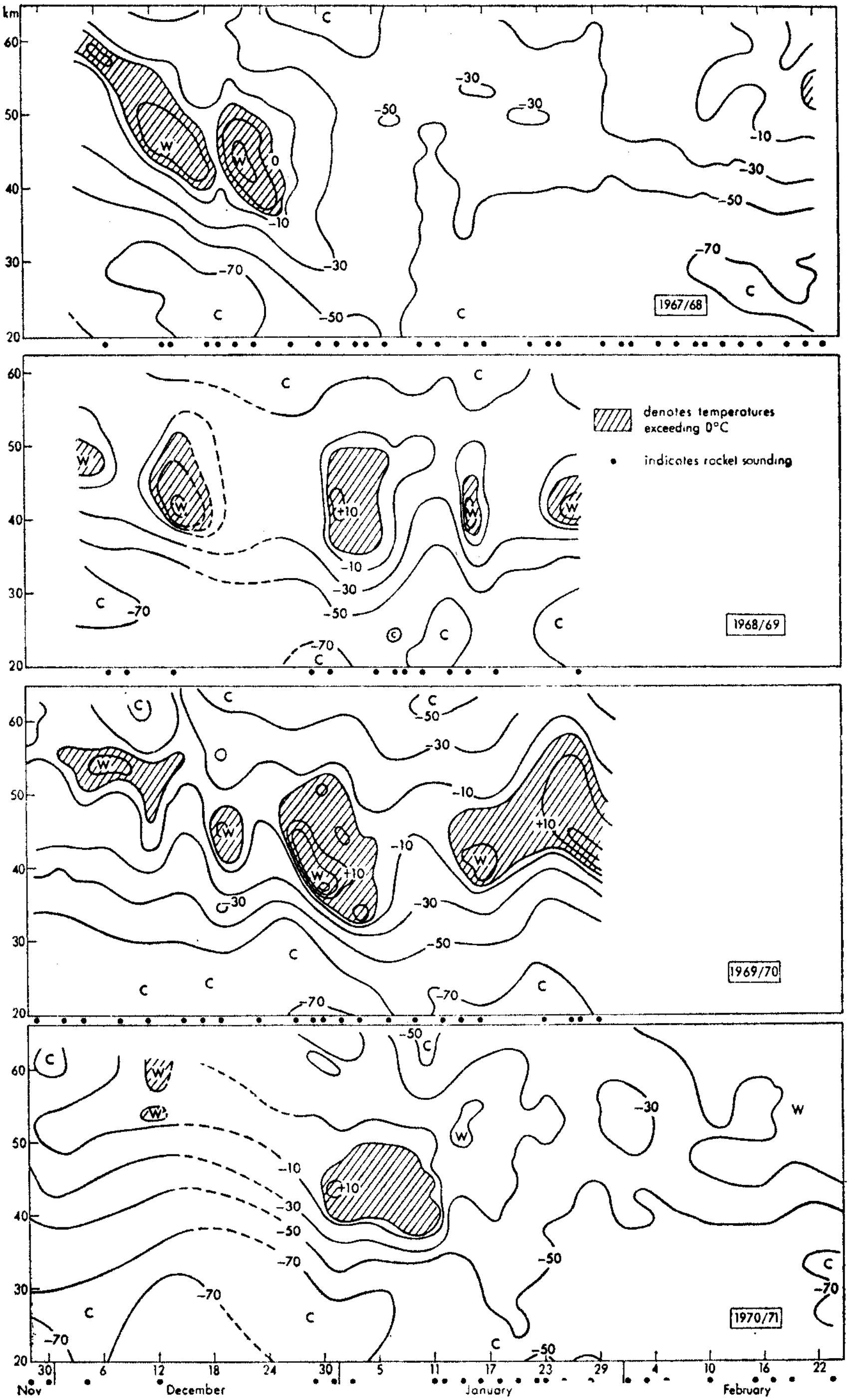

FIGURE 1—HEIGHT–TIME CROSS-SECTIONS OF TEMPERATURE (°C) AT WEST GEIRINISH FOR THE FOUR WINTER CAMPAIGNS BETWEEN 1967 AND 1971

Correction : in 1969/70, late December, the central W isopleth is + 30 not + 50.

in time, until at some point temperature rapidly increased to a value in excess of +10°C, which was then maintained for around three or four days. Cooling then occurred for the ensuing period, again fairly rapidly, as the stratosphere tried to re-establish the original profile, which, although there were further largely minor events, was achieved by the end of February. The winters of 1967–68 and 1970–71 were similar inasmuch as there appeared to be only one major warming event, each during the latter part of December. Following the warming a large portion of the lower stratosphere became near isothermal at temperatures of around −50°C, together with an unusually cold stratopause at around 55 km, then, after a period of about three weeks, a steady return to a more normal profile was observed.

The winters of 1968–69 and 1969–70 however, exhibited a different characteristic inasmuch as there were several bursts of warming, the maximum values of which were similar to other years, but without any major breakdown to follow. The height of maximum warming in all cases shown was around 40–45 km with a very large negative lapse rate of temperature below. The behaviour of the cold regions around 30 km was also similar during the winter from year to year, reaching a minimum of around −75 to −80°C about two days prior to the main warming event. They descended to around 25 km during an event but returned to their original level with a value of −65 to −70°C by the end of February. Further cold zones were found at around 60 km (in fact temperature fell steadily above this height to a minimum of around −90°C at 80 km) about nine days after the maximum warming, although during the winter of 1968–69 the effect was less marked.

Figure 2 shows the zonal wind components over West Geirinish during the last four winters, and large-scale fluctuations are again very much in evidence. It is worth remembering at this stage that these observations are for one location only and therefore no definite synoptic interpretation can be applied to them. The observations appear to sample a region of high winds circulating around the polar vortex, as speeds in excess of 150 m/s were not uncommon—mainly confined to the 50-km region. The winters of 1967–68, 1969–70 and 1970–71 exhibited a similar breakdown in flow pattern around the end of December. Wind velocity increased to a certain maximum value at about the time of the warming, with the increase spreading down through a great depth of the stratosphere, then rapidly decreased over a period of four to six days to around zero or even negative values, again over a similar depth. As the warming diminished, a recovery to the normal zonal flow pattern was achieved, though not without further less-dramatic perturbations. Reversal of flow occurred at high altitudes initially, then gradually spread down to the 25-km level over a period of about 10 days. The cross-section for 1968–69 showed none of the complete flow disruption characteristics of the other years. There may have been some tendency to disruption in early December but this was rather divorced from any warming. Westerly zonal flow persisted throughout the stratosphere fluctuating from around 150 m/s to 50 m/s at 50 km in three rather regular bursts, whilst between 25 and 35 km remarkably constant values were evident.

Cross-sections of meridional flow, not depicted in this note, showed zero or small negative values (i.e. a flow from north to south) below 35 km, but marked fluctuations of both negative and positive values above. Largest values (75 m/s) occurred at the time and level of zonal wind maximum,

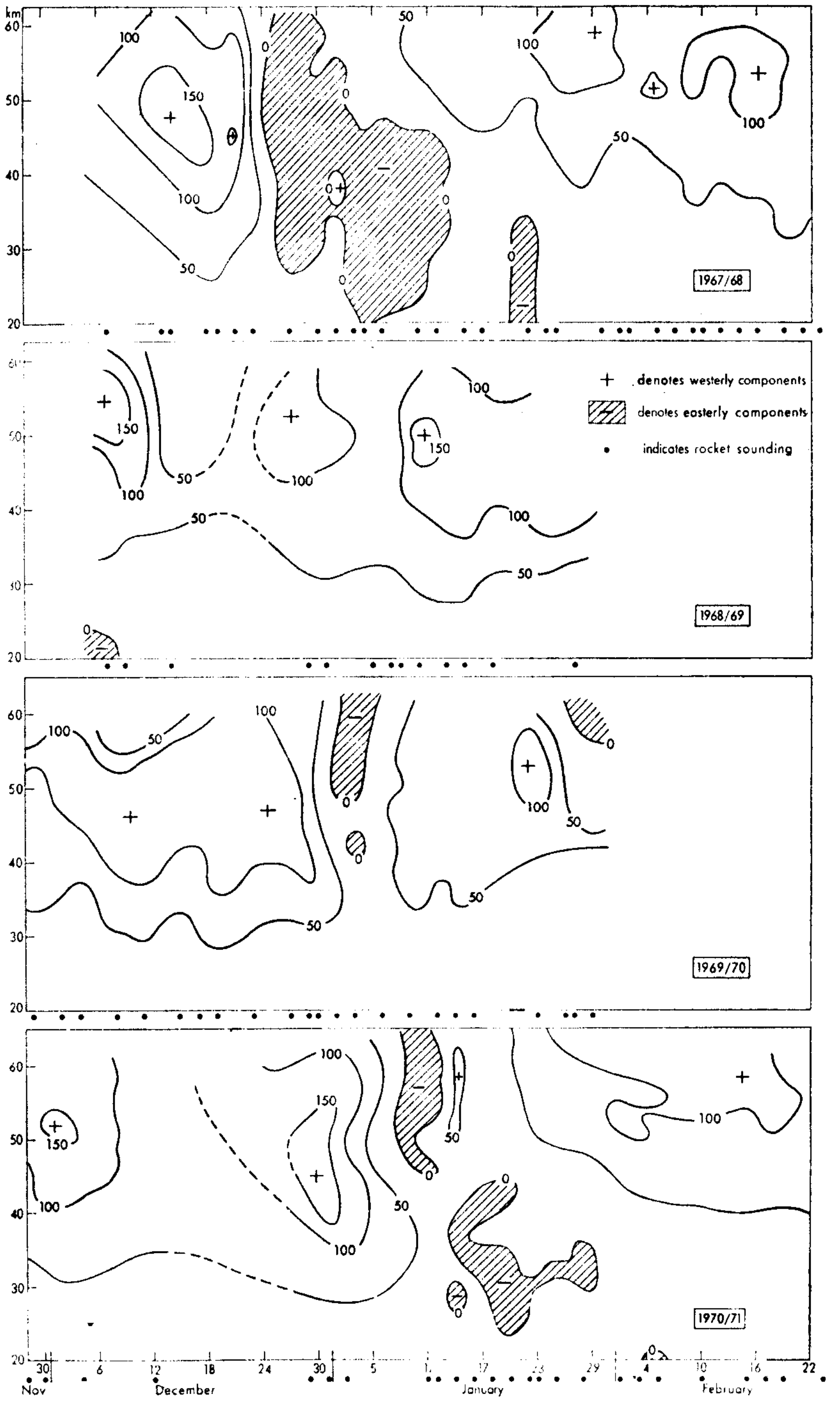

FIGURE 2—HEIGHT–TIME CROSS-SECTIONS OF ZONAL WIND (m/s) AT WEST GEIRINISH FOR THE FOUR WINTER CAMPAIGNS BETWEEN 1967 AND 1971

immediately prior to and slightly above the level of maximum warming. These values were always positive, indicating a backing in the flow preceding the event.

Table I presents mean and standard deviations of temperature and zonal wind at various heights for the three winter months, December, January and February, as well as giving a comparison with the values for 60°N as quoted in the COSPAR International Reference Atmosphere (CIRA) 1965.[2] The very large fluctuations in both temperature and zonal wind which occur in December and January are illustrated clearly by the standard deviations,

TABLE I—SUMMARY OF MONTHLY TEMPERATURES AND ZONAL WINDS AT WEST GEIRINISH FOR THE FOUR WINTER PERIODS 1967–71

	Temperature						Zonal wind				
Height *km*	*N*	Mean	*SD*	Coldest	Warmest	CIRA	*N*	Mean	*SD*	Strongest	CIRA
			degrees Celsius						*metres/second*		
					DECEMBER						
65	8	−27	9	−70	1	−39					
60	23	−22	13	−45	11	−46	13	81	34	117	58
55	26	−13	18	−40	10	−31	23	96	50	184	55
50	27	− 6	23	−23	12	−20	26	105	57	172	51
45	27	− 6	19	−44	29	−28	27	102	51	180	45
40	27	−20	10	−60	25	−42	27	84	41	175	38
35	27	−43	12	−72	− 4	−52	29	62	29	100	28
30	27	−65	14	−85	−27	−57	29	41	18	69	16
25	27	−73	22	−84	−49		29	27	12	38	
					JANUARY						
65	10	−39	11	−57	−23	−40					
60	30	−34	11	−54	− 8	−45	19	49	49	130	52
55	36	−23	14	−44	17	−36	29	60	43	124	40
50	37	−17	18	−47	28	−23	32	60	46	168	30
45	38	−17	23	−49	34	−33	33	49	45	144	23
40	39	−23	24	−58	16	−46	34	38	43	130	18
35	39	−39	19	−68	−22	−54	38	29	32	96	14
30	39	−53	10	−72	−27	−60	39	19	23	64	8
25	39	−62	9	−79	−41		42	15	15	42	
					FEBRUARY						
65	5	−23	10	−33	− 8	−38					
60	18	−19	9	−35	0	−40	10	87	21	131	27
55	22	−15	11	−32	18	−35	22	95	19	124	17
50	23	−18	8	−30	− 2	−23	23	91	10	111	7
45	23	−26	10	−42	− 6	−33	23	71	13	93	− 3
40	23	−45	7	−55	−29	−46	23	50	16	84	− 7
35	23	−61	5	−69	−53	−55	23	32	13	65	− 3
30	23	−67	4	−75	−61	−61	23	24	12	46	7
25	23	−66	5	−73	−57		23	15	10	34	

Note :
Height = height of the observation in kilometres.
N = total number of observations.
SD = standard deviation.
Coldest = coldest value recorded in the month during the four winter periods.
Warmest = warmest value recorded in the month during the four winter periods.
Strongest = highest wind speed recorded in the month during the four winter periods.
CIRA = COSPAR International Reference Atmosphere 1965.[2]

which indicate how little significance can be attached to a mean value during this period, especially in the 40–55-km region. Smaller variation occurs in February as more-normal flow patterns and temperature profiles become established again in the stratosphere. Quite large differences occur between the mean values and those quoted from CIRA. The latter were compiled mainly from data obtained in the U.S. Meteorological Rocket Network and relatively few soundings in other parts of the northern hemisphere. Over the whole period the mean temperatures above 40 km at West Geirinish were significantly higher than CIRA values, this difference occasionally exceeding one standard deviation, especially in December. The effect of the warm Aleutian high on the Canadian stations of Fort Greely, Primrose Lake and Fort Churchill which strongly influence the CIRA values for the latitude of U.K., probably account for the difference in values at 30 km. Large differences also appear in the values for zonal wind, especially in February. Wind reversals in December and January again render the standard deviations so large that a true mean value cannot be assessed. The Canadian observations, which seem to sample a slacker régime than that over West Geirinish in February, are responsible for the differences occurring during that month.

Discussion. There is a difficulty in trying to evaluate whether changes shown by the observations at West Geirinish are purely dynamic, advective or both, but large-scale fluctuations in temperature and wind do exist in the stratosphere during the winter months at latitudes in the vicinity of the U.K. An indicated warming of the higher stratosphere must be regarded as a sample of a large area, frequently centred over north-west Europe, but only detected several days later at 30 km by balloon observations, suggesting a gradual warming downwards through a great depth. Mean temperatures for specific layers of the stratosphere measured by satellite indicate a gradual migration of the warm area north or north-westwards towards the pole, and if, as in the case of the Aleutian warm high, there is a westward tilt with height, some of the downward motion could be attributed to movement towards the tilt.

Since the discovery by Scherhag[3] in 1952, of the stratospheric sudden warming, many such events have been investigated, but their inception is still not understood. Vertical motion has to be regarded as the prime mechanism for such temperature changes (in excess of 30 degC in three or four days), being produced by developing systems within the main flow pattern. By early December the northern hemispherical flow has a wave number one characteristic with the establishment of a high in the area of the Aleutian Islands and the displacement of the polar vortex towards Eurasia. Thereafter the vortex begins to elongate and a wave number two characteristic appears in the flow. Hirota[4] has produced a model which shows that a small disturbance injected into such a flow will rapidly develop until the flow becomes completely distorted and the number two characteristic is destroyed. Whether the injection mechanism is induced from below, that is by tropospheric events permeating through the tropopause and affecting the lower stratosphere, or from above, by disturbances in the mesosphere, is not yet understood. Another theory is that bursts of high energy solar radiation,[5] upsetting the photo-chemical balance of temperature in the upper stratosphere, may well have some influence in initiating a disturbance in a potentially unstable environment.

Detailed analysis of the circulation and temperature structure of the stratosphere can only be achieved from a network of rocket observations around the world. Unfortunately, such observations are very meagre indeed over Europe and Asia, as shown in Figure 3, and as a consequence, an assessment of the state of the stratosphere to any degree of accuracy is not possible in these areas. The advent of satellites measuring mean temperatures of discrete layers of the stratosphere offers some hope of filling gaps in the network, and hence increasing Man's knowledge of a region of the earth's atmosphere still containing many enigmas.

Acknowledgements. The author wishes to acknowledge the continued invaluable assistance of the Commandant, Royal Artillery Range, South Uist.

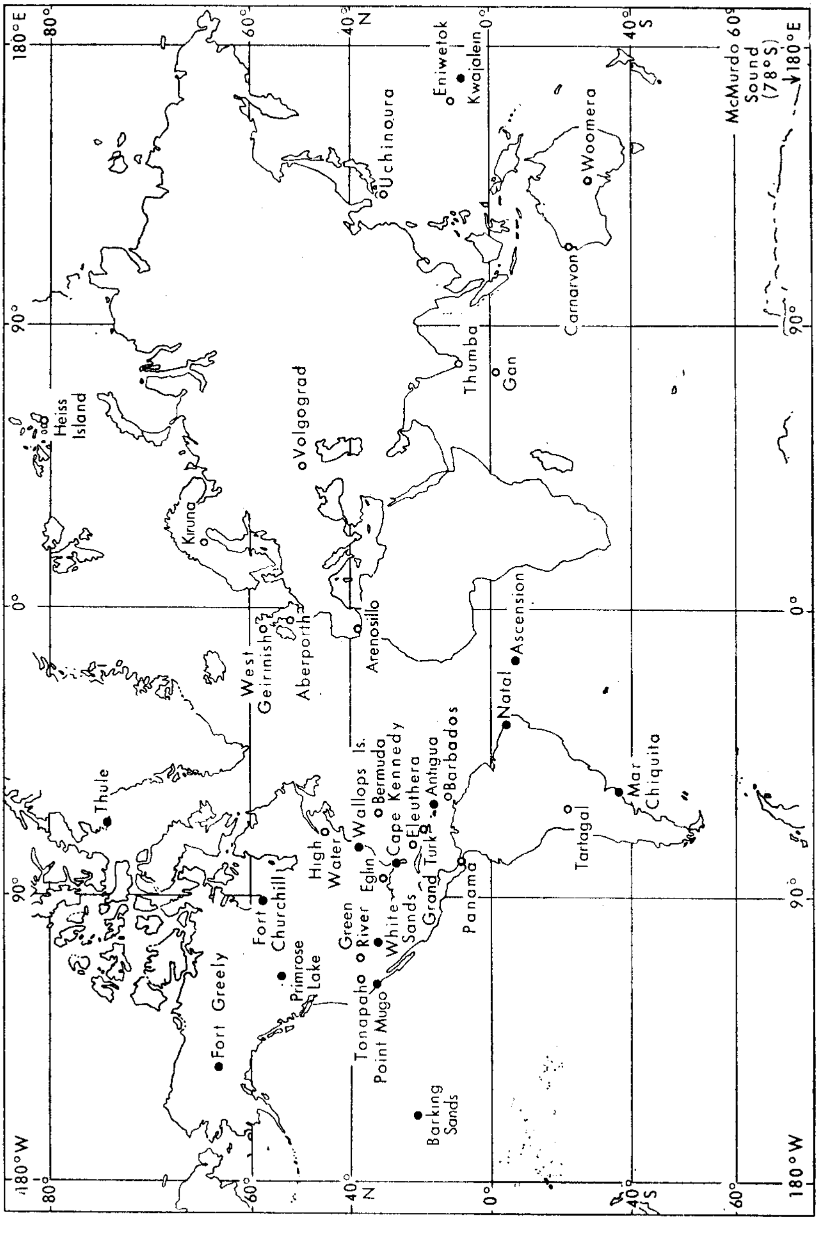

FIGURE 3—METEOROLOGICAL SOUNDING ROCKET STATIONS

● Regular reporting station (throughout the year)

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REVIEWS

Planetary atmospheres, edited by C. Sagan, T. C. Owen and H. J. Smith. 244 mm × 175 mm, pp. xviii + 408, *illus.*, D. Reidel Publishing Company, P.O. Box 17, Dordrecht–Holland, 1971. Price: Dfl.75.

The growing interest in the study of the composition, structure and circulation of planetary atmospheres is a direct consequence of better observations and advances in the theoretical and experimental study of basic chemical, physical and dynamical processes. Until a few years ago only a few astronomers were interested in the subject, but, as with other branches of planetary sciences, the study of planetary atmospheres is now developing links with its Earth Sciences counterpart, in this case meteorology, with benefits all round.

International Astronomical Union Symposium Number 40 was held in Marfa, Texas, in October 1969 on the subject of planetary atmospheres and was attended by more than 100 experts from several countries but mainly from the U.S.A. and U.S.S.R. The book under review is a collection of articles presented at the symposium, the programme of which showed a strong bias towards composition and structure, with comparatively little dynamics. The first and second parts of the book are sections of roughly equal length devoted to Venus and Mars respectively, and the third section, which is less than half the length of the first and second, deals with the outer planets, Jupiter, Saturn and Uranus. The fourth section is a six-page account of the scientific dedication of the 107-inch reflector at the McDonald Observatory.

The lack of coherence in such a wide and complicated subject at its present stage of development is reflected in this book, but some of the articles are valuable for the new observational material they contain. A meteorologist will find much to interest him, especially if he is prepared to brush up his basic chemistry and physics and to reflect a little on the underlying principles of his own field.

R. HIDE

Earthquake displacement fields and the rotation of the Earth, edited by L. Mansinha, D. E. Smylie and A. E. Beck. 244 mm × 170 mm, pp. xi + 308, *illus.*, D. Reidel Publishing Company, P.O. Box 17, Dordrecht–Holland, 1970. Price: Dfl.65.

The geographic positions of the Earth's poles of rotation undergo slight but detectable variations, including the so-called free 'Chandler wobble'. As Lord Kelvin pointed out in the last century, the difference between the observed wobble period of 14 months and the 10-month period of a perfectly rigid spheroid with the same rotation period and shape as the Earth is a measure of the Earth's mean rigidity, which is comparable with that of steel.

Geophysical interest in the Chandler wobble centres nowadays on possible excitation mechanisms. Earthquakes are associated with a redistribution of matter within the Earth and it is an old idea that this redistribution might *inter alia* produce the Chandler wobble. This idea encounters quantitative difficulties, but these were reduced considerably a few years ago when F. Press suggested that the displacement field associated with a major earthquake may extend over much greater distances — thousands of kilometres — than had previously been supposed and L. Mansinha and D. E. Smylie subsequently discovered that very large earthquakes apparently correlate quite well with changes in the centre of polar motion. A consequence of the renewed interest in the idea and in related geophysical problems was the North Atlantic Treaty Organization Study Institute held in June 1969 at the University of Western Ontario, London, Canada, on the subject of earthquake displacement fields and the rotation of the Earth.

The book under review is a collection of articles presented at the conference, the scope of which was rather wider than the title of the book implies. The first article is a brief review of observations of the rotation pole and attempts to explain them. This is followed by two articles on earthquake displacement fields, including both theory and observations. The remainder of the book falls into four main sections, on present day measurement and analysis of rotation and polar motion (seven articles), excitation of the Chandler wobble (eight articles), the observation of deformation fields (eight articles) and precise measurement of the Earth's rotation and polar motion by new methods (two articles).

Most of the articles are valuable up-to-date additions to the geophysical literature and the book contains a short subject index. Doubtless through an oversight, the alphabetical name index excludes about a quarter of the alphabet without discontinuity in pagination.

R. HIDE

Interstellar gas dynamics, edited by H. J. Habing. 244 mm × 175 mm, pp. xxiii + 388, *illus.,* D. Reidel Publishing Company, P.O. Box 17, Dordrecht–Holland, 1970. Price: Dfl.75.

Astrophysicists are interested for a variety of reasons in the dynamical behaviour of interstellar gas, and symposium number 39 of the International Astronomical Union, organized jointly by the IAU and the International Union of Theoretical and Applied Mechanics and held in September 1969 at Yalta in the Crimea, was devoted to the subject. The book under review 'is supposed to [present] what was actually reported and discussed [at the conference, but] in a polished and organised way'.

The book contains the following fifteen invited review papers: 'Review of cosmical gas dynamics' by H. C. van de Hulst; 'Some characteristics of interstellar gas in the Galaxy' by H. F. Weaver; 'Theoretical description of the interstellar medium' by G. B. Field; 'Collective plasma phenomena and their rôle in the dynamics of the interstellar medium' by B. B. Kadomtsev and V. N. Tsytovich; 'Observational aspects of galactic magnetic fields' by G. L. Verschur; 'The origin and dynamical effects of the magnetic fields and cosmic rays in the disk of the Galaxy' by E. N. Parker; 'The gas dynamics of accretion' by E. A. Spiegel; 'Mass balance of interstellar gas and stars' by E. E. Salpeter; 'Supernovae and the interstellar medium' by L. Woltjer; 'The solar wind — an example of a cosmical plasma and a stellar wind' by R. Lüst; 'Mass loss from stars' by S. R. Pottasch; 'Mass loss from eruptive stars' by A. A. Boyarchuk; 'Interstellar gains and spiral structure' by J. M. Greenberg; 'Interstellar molecules' by T. P. Stecher and E. E. Salpeter; and 'Protostars and other neutral condensations in H II regions' by P. G. Mezger. Each one of these review papers led to a lively and extensive discussion at the conference and the reports of these discussions occupy over one-quarter of the whole book.

The organizers of the conference did well in persuading so many leading workers to review their respective fields at the same meeting and the resultant book is consequently an authoritative account of this important if highly specialized subject. This reviewer has often heard astrophysicists working on fluid dynamical problems complain that dynamical meteorologists employ jargon too freely, but the meteorologist will doubtless find terms like 'elephant trunks' (the only item under 'e' in the subject index) singularly unenlightening unless he happens to be familiar with certain characteristic features of the interstellar medium. The specialist, however, for whom this book was produced will find it an indispensable addition to his library.

R. HIDE

LETTER TO THE EDITOR

Lightning strike on a tree near the Meteorological Office, Bracknell

On 19 August 1971 at 1601 GMT lightning struck one of a pair of Wellingtonia pine trees growing in front of Coppid Hall, Warfield Road, Bracknell, about 250 yd north-west of the Meteorological Office Headquarters. The top 30 ft of the tree was shattered into many pieces and the trunk was split for a further 25 ft (Plate I). The damaged tree, the highest in the neighbourhood, was about 15 ft higher than the neighbouring pine tree which is approximately 100 ft high. Plate II shows the trees as they were in 1965 and Plate III shows how the taller tree on the right appeared after the strike. The tree had to be cut down and from cross-sections of the trunk it was found that the damage extended right down to the base. Specimen cross-sections are shown in Plates IV and V.

When I examined the trees on 20 August I noticed that the other pine tree had two lightning scars on the side of the trunk facing the damaged tree stretching from a height of about 40 ft to within 10 ft of the ground (see Plate VI). It would appear that where the branches of the two trees met, just below the break, at least part of the current was transferred from one tree to the other.

The lightning strike was seen by a number of Meteorological Office staff and I quote below the most detailed one, by Mr J. C. McGovern who happened to look up from his desk a few moments before the strike. He was about 245 yd from the tree.

'On 19 August 1971 at 1600 GMT thunderstorms developed along a line from Bracknell to between Wokingham and Yateley. At 1601 GMT a lightning flash, with an earsplitting detonation, discharged from cumulonimbus, base estimated at 3000 ft.

The lightning bolt struck the furthermost of twin, conical pines on the Warfield road. For an interval of a few seconds the whole tree was enclosed in a brilliant, white light with a narrow red streak running earthwards down the trunk. The tree, particularly in the top-most section, began to shake and shiver violently; then, perceptibly, the stronger branches burst apart depositing 6–10 ft (later measured as 30 ft) of the cone on the footpath and roadway.'

At the time of the lightning there was 7/8 cloud coverage — 4/8 cumulus, estimated base 2800 ft and 3/8 cumulonimbus, bases estimated at 3000 ft. Wind conditions at the time were calm. Visibility was 3 miles with slight rain.

Mr P. Wescott was on the roof of the Office, just above Mr McGovern's room and his account is given below.

'I was on the roof, feeling quite safe, as the nearest lightning was probably ¾ mile away to the south-west. The storm was moving slowly north-westwards, with the anvil edge overhead. Only a few spots of rain occurred at the Office during the storm. The lightning was exceptional as it must have come either from the anvil or travelled outwards from the storm. The Office seemed completely surrounded by lightning with dozens of "branches" to it, with the main strike seeming to hit the tree, the top of which toppled off, having been split vertically. The thunder was a very loud bang almost instantaneous with the lightning.'

Mrs D. Hanington was only a few yards past the tree, walking northwards on the Warfield Road, when she was aware of a vivid flash over her left shoulder, a tremendous crash and a smell of burning wood. A few moments later the shattered top fell into the road a few feet behind her.

A number of eye witnesses have commented on the width of the flash — 'a fairly broad band and not very jagged' and all agree that there was either no rain or just a few small spots at the time. There are varying reports of the colour of the lightning, a number of witnesses recall it as 'blue' or 'vivid purple-blue' whilst one witness saw a red flash and not the blue colours he had seen in others, but he experienced no dazzle effect or after-image. Mrs Gaines described it as the colour of gold and said the air seemed to sizzle as she stood in Deepfield Road near the old people's bungalows. Mr Folland saw red flames 1–2 ft long licking the base of the decapitated tree head as it began to fall.

The CRDF section at Beaufort Park near Bracknell recorded 14 major lightning flashes in the area between 16 and 17 GMT.

I would suggest that the most interesting feature of this account is the report by Mr McGovern, a trained observer of many years' experience, who saw the tree 'enclosed in a brilliant white light'. I must admit that I wondered whether this was an 'after-image' effect until some weeks later I received *Weather** for September 1971, where there is a remarkable colour photograph

* ORVILLE, R. E.; Close lightning. *Weather, London*, **26**, 1971, pp. 394–395.

of a tree being struck by lightning and encased in a golden light. Possibly most of the witnesses were not actually looking at the tree at the moment of impact but their attention was drawn to it by the flash. Some of course could not see the tree as it was obscured by a neighbouring building.

Meteorological Office, Bracknell

R. K. PILSBURY

OFFICIAL PUBLICATIONS

The following publications have recently been issued :

Handbook of aviation meteorology. Second edition.

The second edition of this handbook in attempting to reflect the rapid progress that has continued in the fields of aviation and meteorology during recent years, enhances, it is hoped, the basic purpose of the book which is to provide aviators, and others interested in aviation, with a comprehensive and up-to-date guide to the branches of meteorology most suited to their interests.

Considerable rewriting has been done on vertical motion in the atmosphere, especially in relation to standing waves; on instability phenomena and precipitation; and on high-altitude flight conditions. Sections are devoted to new trends in instrumentation and to observations from space satellites, and methods of numerical forecasting in the Office are outlined. Examples have been included showing the use of computer forecasts and satellite pictures.

Although some of the original text relating to fundamental physical principles has been little affected except for minor clarifications, there are few sections of the book which remain completely unaltered.

Geophysical Memoirs

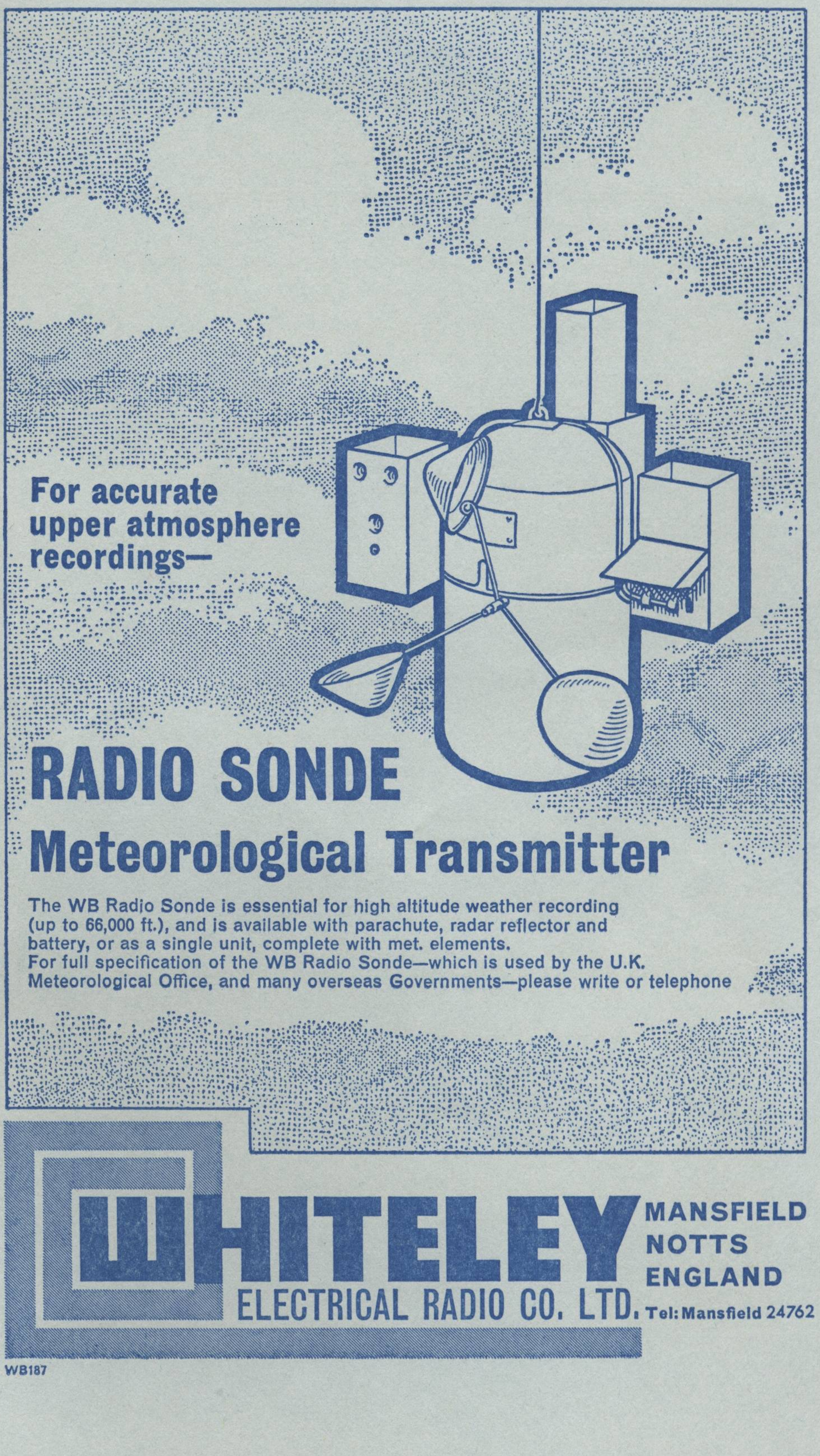
No. 114. Circulation patterns at 850, 700, 500 and 200 millibars over the eastern hemisphere from 40°N to 40°S during May and June. By P. B. Wright, B.Sc. and M. W. Stubbs, B.Sc.

This memoir presents a set of wind flow charts and vertical cross-sections to illustrate the circulation patterns of the troposphere over much of the tropics and subtropics during May and June. During this period the development of the Asian summer-monsoon system is associated with rapid changes in the circulation patterns over southern Asia and adjacent parts of the Indian Ocean. It is demonstrated that the changes that occur in the upper troposphere over areas as far apart as Africa and the western Pacific are probably part of the same development but the seasonal changes in the lower troposphere over Africa occur independently. Variations in the development during each of the years 1956–60 are discussed and it is shown that the patterns of May 1956 exhibited unusual behaviour. A biennial oscillation in several features of the circulation is described. Some relationships with changes outside the tropics are discussed.

No. 115. Mean monthly airflow at low levels over the western Indian Ocean. By J. Findlater.

This memoir contains charts of mean monthly airflow at 3000 ft (1 km) and 10 000 ft (3 km) based on data from 72 pilot-balloon and radar-wind stations known to have operated since 1930. Tabulated mean monthly winds are included for the 3000-ft, 5000-ft, 7000-ft and 10 000-ft levels.

The comprehensive network of mean values allowed streamline and isotach analyses to be made of the detailed structure of the major monsoon currents and the zones of light wind which separate them. Of particular interest is the development during the northern summer of a relatively narrow and high-speed current which circulates near the western limit of the Indian Ocean and links major synoptic features in the southern and northern hemispheres. This current crosses the equator as a southerly wind and its structure is illustrated in vertical cross-sections of mean meridional flow along the equator.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