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A survey of rainfall recording in two regions of the northern Pennines

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Summary

Monthly rainfall records for three areas of the northern Pennines have been analysed for the years of available records. Composite records were produced for Allenheads (Northumberland), Kettlewell (Yorkshire) and Malham Tarn (Yorkshire) back to 1854, 1853 and 1870 respectively. The records are compared with each other and suggestions are made for extending them back further in time.

Introduction

The Pennine Chain, which forms the backbone of England, marks the divide between two distinct precipitation régimes, north-west and north-east England. The former region has enhanced orographic precipitation while the latter is in the rain shadow. All the rivers of northern England have their headwaters in the Pennines, so rainfall variability directly determines the return periods of dry flow sequences and flood flows in both north-western and north-eastern England.

Rainfall recording in the northern Pennines began later than in most other mountainous parts of the British Isles. The lack of rain-gauges at altitudes over 1000 ft (305 m) prior to 1880 is particularly pronounced (see, for example, Symons's (1866) report to the British Association). Two areas where recording began early were the Alston region in the South Tyne valley (Fig. 1(a)) and Kettlewell in Upper Wharfedale (Fig. 1(b)). Both sites possess a sufficient number of rainfall records to enable a composite record to be produced since 1854 at Allenheads (Alston) and since 1853 at Kettlewell. At the headwaters of the River Aire, the valley south of Wharfedale, lies Malham Tarn from where a number of rainfall records are available (Fig. 1(b)). These are combined into a third composite Pennine record.

Rainfall recording in the Alston region of Cumbria

Table I lists the rain-gauges that have operated within 15 miles of Alston that were considered important for the construction of a composite record to represent the region. The list is almost certainly complete up until about 1900. After this, and particularly during the last 20 years, only a selection is given. Table I lists only the principal observer or observers and the main height above mean sea level at which the gauge was operated. At a number of sites the observer and gauge height change frequently, especially from one 10 year sheet to the next. Only changes which have affected the gauge catch are noted in the text. Fig. 1(a) shows the relative positions of the gauges. The construction of the composite

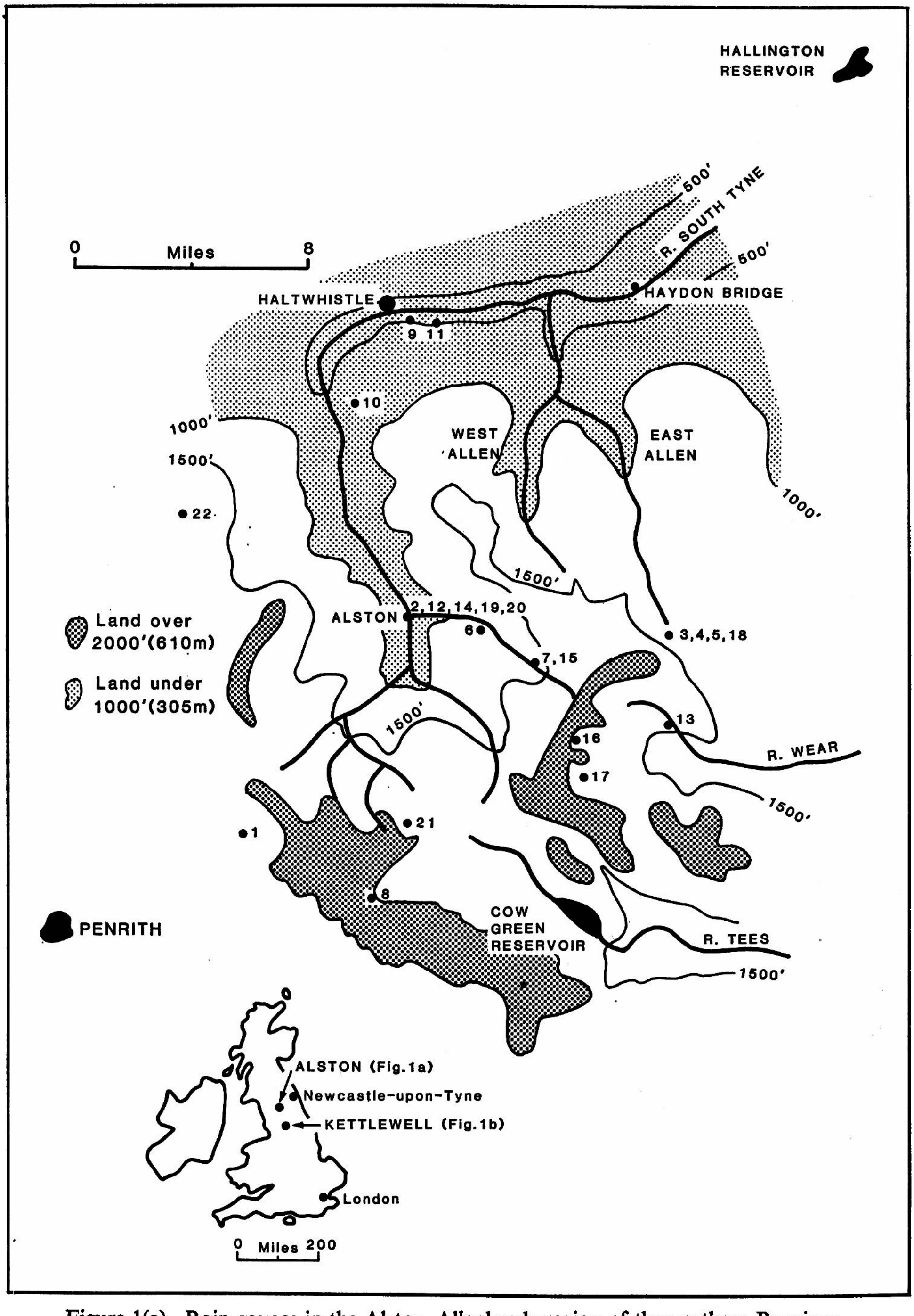

Figure 1(a). Rain-gauges in the Alston–Allenheads region of the northern Pennines.

Table I. *Rain-gauges in the Alston region of Cumbria*

Gauge No.	Gauge name	First year	Last year	Missing years	Height *metres*	Observer(s)
1	Crewgarth (nr Ousby)	1835	1852		?	Mr J. P. Spedding
2	Alston	1851	1852		?	?
3	Allenheads 5 in above ground	1854	1885		412	M. Varty, Esq.
4	Allenheads 6 ft 9 in above ground	1852	1872	1867–69, 1871	417	M. Varty, Esq.
5	Allenheads	1837	1846	1844	427	Rev. W. Walton
6	Alston Love Lady Shield	1863	1894	1870–74, 1886–91	351	J. Dickinson
7	Nenthead	1866	1869		432	W. Dalton
8	Hurth Syke	1876	1879		610	Mr J. Todd
9	Haltwhistle Unthank Hall	1869	1900		116	Rev. D. Dixon Brown
10	Haltwhistle Shaft Hall	1879	1893		191	R. Hetherington
11	Haltwhistle Bellister Castle	1906	1918		116	J. M. Clark, Esq.
12	Alston (nr Church)	1889	1891		265	?
13	Wearhead	1899	1909		377	Mr R. Rust
14	Alston Lowby Manor House	1907	1910		280	J. R. Walton
15	Nenthead	1901	1919		446	Caldwell Harpur
16	Wellheads Hush	1901	1964	1902–22 } Annual totals only	515	N.W.A.
17	Grassmeres	1901	1977	1902–22 } Annual totals only	564	N.W.A.
18	Allenheads	1910	1977	1919, 1937, 1971–72	411	various
19	Alston Vicarage	1931	1952		287	Rev. N. A. Walton
20	Alston King Samuel School	1970	1974		290	?
21	Moor House	1953	1977		556	Nature Conservancy Council
22	Geltsdale	1898	1977		229	City of Carlisle then N.W.W.A.

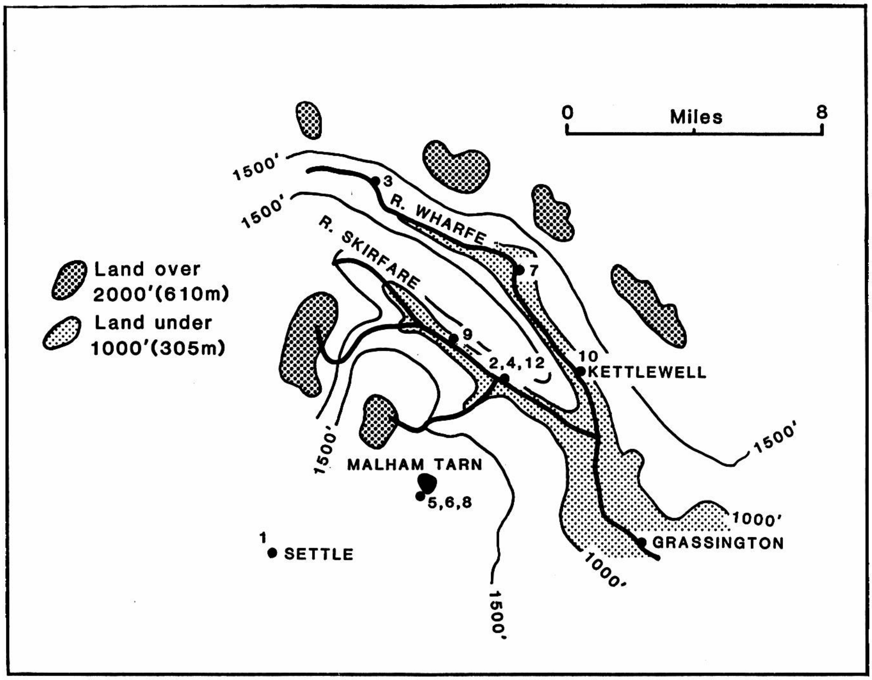

Figure 1(b). Rain-gauges in Upper Wharfedale.

record follows the pattern of previous work by Craddock (1977) and Jones (1980) in that conversion factors are produced from comparisons of the time series of the ratio of annual catches. The ratio should vary about a straight line, any change being due to a change in the gauge, its location or its environment.

Selection of key site

The choice of a key site for this region is between the four sites (Nos 17, 18, 21 and 22) where recordings have been made for at least 25 years. The site at Geltsdale (No. 22) was moved during 1962 without an overlap period. The site at Allenheads (No. 18) ceased operation during 1971 when the record was not kept for some months. However, a new site (also No. 18, and treated as the same site as the gauge kept from 1910–70) was introduced in 1972 by the Northumbrian Water Authority. As well as a daily rain-gauge, a Fisher and Porter punched tape autographic recorder was installed. The site at Moor House (No. 21) at an altitude of 556 m is in a rather exposed position. A detailed description of this site is given by Manley (1980). The Grassmeres gauge (No. 17) situated in the catchment area of Burnhope reservoir in Weardale is only read at monthly intervals and is thus prone to errors that can occur with this type of record, e.g. undetected leakage or damage. Between 1902 and 1922 only annual totals are available for the Grassmeres gauge. Thus, none of the sites is ideal as a key site for a variety of reasons. As early records are available at Allenheads (Nos 3, 4 and 5), the first lasting from 1854 to 1885, Allenheads (No. 18) was chosen as the key site. Furthermore, as far as can be gained from the Meteorological Office Archives, site No. 3 was very near to the key site (No. 18) record. This site has the added advantage of having two gauges operating, the normal daily gauge and the autographic one.

Construction of composite record

The earliest rainfall record in the region was kept at Crewgarth near Ousby in Cumbria (No. 1) on the western side of the Pennine Ridge from 1835 to 1852 by Mr J. P. Spedding. The first record in Alston (No. 2) was kept for two years from 1851 to 1852 by an unknown observer. It is, therefore, difficult to assess the Crewgarth readings, but a record was located in Penrith (see Fig. 1(a)) and the Crewgarth gauge caught about 72% of the Penrith gauge catch during the overlap period 1836–39 and 1851–52.

A record from Allenheads (No. 5) from 1837 to 1846 was kept by the Rev. W. Walton (referred to below as Allenheads 'W'). Annual values only are available, however, for the years 1840, 1843, 1845 and 1846, with no values at all for 1844. Little is known about this record and the source is given in the 10 year sheets held at the Meteorological Office as 'Manuscript, held by the Meteorological Society' on one decade sheet and on the other as 'Atkinson's Maps'. Many sheets during this period in northern England often refer to the source 'Atkinson's Maps'. Symons (1866) refers to Mr Joseph Atkinson of Harraby, near Carlisle, who published rainfall maps for the British Isles for 1841 and 1842 at least. Symons was unable to obtain a copy of this in 1866, but from the number of references to Atkinson's Maps in the 10 year sheets it can be assumed that he did so at some later date. For the years available between 1837 and 1846, the Allenheads 'W' gauge caught almost twice as much as the Crewgarth gauge during their nine years of overlap.

Later records at Allenheads cover the period from 1853 to 1885 and in the 10 year sheets are referred to as 'not compatible with the Allenheads record from 1910 to 1977'. However, on examination of the record it becomes obvious that the first observer, Thomas J. Bewick, was operating two gauges: a 12 inch diameter gauge, 6 feet 9 inches above the ground (site No. 4, the Allenheads 'post' record), and an

8 inch gauge, 5 inches above the ground (site No. 3, the Allenheads '8 inch' record). The former operated from 1854 to 1866 and again from 1870 to 1872 while the latter ran from 1853 to 1885. A change of observer during the late 1860s, when Matthew Varty continued the record may explain the termination of the 'post' record shortly afterwards. Fig. 2 shows the comparison of the annual catches of the two gauges for the years between 1854 and 1872, revealing that the larger 'post' gauge caught approximately 9% more than the smaller, conventionally sited gauge.

The location of both gauges during the 1860s and 1870s is almost certainly the same, and distances from nearby churches, gauge heights and wall positions of these gauges suggest that the site is very similar to that of the later records at Allenheads from 1910 (site No. 18). This impression is gained on two counts from the 10 year sheets at the Meteorological Office. Firstly, the gauges are at *exactly* the same surveyed heights. Secondly, gauge position for the records from 1854–85 and from 1910 onwards indicate that both are in the walled garden of a house two miles south of St Peter's Church, Allendale.

Figure 2. Ratio of annual catches, Allenheads (8 in, 5 in above ground): Allenheads (12 in, 6 ft 9 in above ground.) $\bar{x} = 0{\cdot}915$.

During the 1860s a number of records started in the South Tyne Valley: at Love Lady Shield (No. 6) (four miles south-east of Alston in the Nent Valley, by Mr Dickinson) for various periods from 1863 to 1894; at Nenthead (No. 7) from 1866 to 1869; and at Unthank Hall (No. 9), Haltwhistle, from 1869 to 1900—a record kept by the Rev. D. Dixon Brown. Fig. 3 shows the comparison of the longer Allenheads (1854–85) record (No. 3, 8 inch diameter, 5 inches above ground level) with the Unthank Hall (No. 9) record. The Allenheads record (No. 3) used in Fig. 2 has been shown to be in good agreement with the 'post' record (No. 4) until 1872. The Allenheads annual rainfall totals are less than those at Love Lady Shield (No. 6) only for the years between 1880–85, except 1881, thus these records must be considered unreliable and can only be used until 1879. Fig. 3 suggests that the Unthank Hall and Allenheads records are in good agreement during the 1880s, thus indicating the need to perform all possible comparisons. If the Unthank Hall (No. 9) is compared with that about 25 miles north-east at Hallington Reservoir (unnumbered, see Fig. 1(a)) then the totals for the period 1869–78 are low. This discrepancy in the Unthank Hall records can be partially confirmed with Love Lady Shield records although the number of overlap years is small.

In 1879 a record started at Shaft Hall (No. 10) near Lambley about six miles north of Alston. It would be preferable to use this record in preference to Unthank Hall to cover the unreliable part of

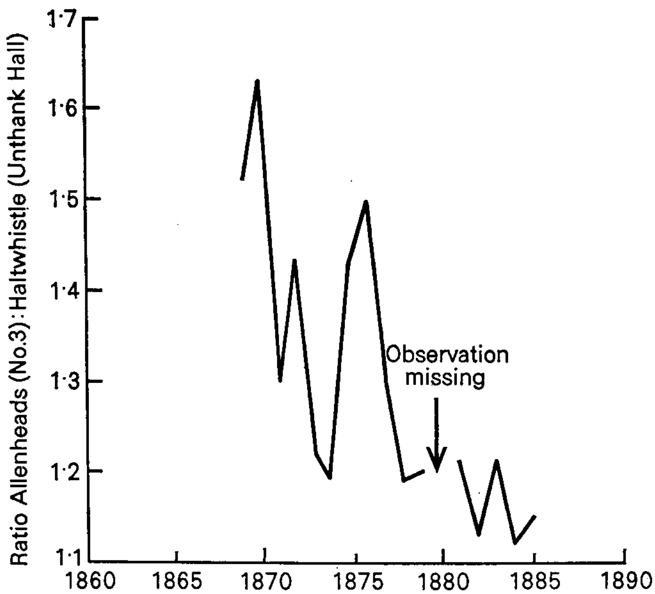

Figure 3. Ratio of annual catches, Allenheads (No. 3): Haltwhistle (Unthank Hall). $\bar{x}$ (1869–79) = 1·352, S.D. = 0·16. $\bar{x}$ (1869–85) = 1·277, S.D. = 0·16.

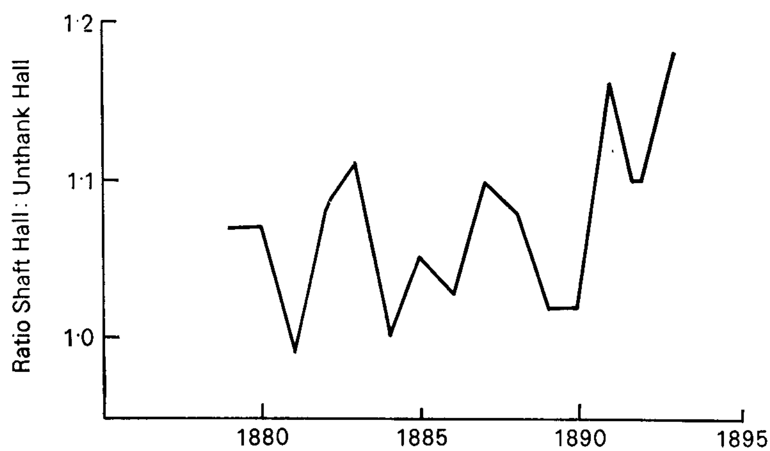

Figure 4. Ratio of annual catches, Shaft Hall: Unthank Hall. $\bar{x}$ = 1·070, S.D. = 0·055.

the Allenheads record as it is significantly nearer Allenheads. Fig. 4 shows that the record is in good agreement with Unthank Hall and that it can be used for the composite record, from 1880, the date from which the Allenheads record is suspect, until 1893. It is preferable to use only a small number of records when building up a composite record. For this reason the Love Lady Shield record, which is rather fragmentary and which may have occupied different sites during its period of operation, is only used for comparison purposes. Between 1895 and 1898 the only gauge operating in the region is that at Unthank Hall, so this record must be used. The composite series up to 1898 is made up of Allenheads (No. 3) for 1854–79, Shaft Hall (No. 10) for 1880–93 and Unthank Hall (No. 9) from 1894 to 1898.

In 1898 the Geltsdale (No. 22) record begins, and in 1899 so does a record from Wearhead (No. 13) across the catchment divide, five miles to the south of Allenheads. In 1901 another record begins at Nenthead (No. 15), a village five miles south-east of Alston. For the period from 1910 to 1919 this gauging overlaps with the key site at Allenheads. An interesting feature regarding the Nenthead (No. 15) record kept by Caldwell Harpur is that all the measurements were made in millimetres and the height of the gauge surveyed in metres. All these records were converted to inches and feet by the British Rainfall Organization. Fig. 5 compares Nenthead and Wearhead. Further comparison with Grassmeres (No. 17) indicates that the records for Nenthead are too low for the first four years (1901–04). The composite record therefore uses the Nenthead record from 1905, and the Wearhead record from 1899 to 1904. Using these two gauges between 1899 and 1909 is preferable to using the Geltsdale (No. 22) record since the latter is much farther from the key site at Allenheads. As was stated earlier, only annual values are available at Grassmeres for the years 1902–22.

After 1910, the Allenheads record is available and this forms the basis of the composite series. Internal consistencies can be checked by comparisons with Alston Vicarage (No. 19) (Fig. 6), Grassmeres (No. 17) and Moor House (No. 21). The comparisons indicate that the catch at Allenheads was about 10% lower before 1940 compared with the period thereafter. No move is mentioned in the 10 year sheets but a change from an eight inch to a five inch diameter gauge is noted. In the 10 year sheets stored at the Meteorological Office it is pointed out that, for the years before 1940, the annual totals are consistently low. The composite record will therefore need to increase the record for the period from 1910 to 1940 and the years when the record is incomplete, 1919, 1937 and 1971–72 must be filled by Nenthead (No. 15), Alston Vicarage (No. 19) and Alston King Samuel School (No. 20) respectively.

The conversion factors for the appropriate gauges in the composite record are given here and further details may be found in Appendix 1. Annual rainfall totals for the composite series, smoothed by a nine year binomial filter, are plotted in Fig. 7.

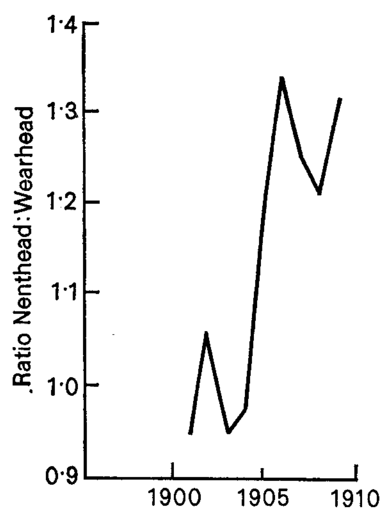

Figure 5. Ratio of annual catches, Nenthead:Wearhead. $\bar{x}$ (1905–09) = 1·274, S.D. = 0·074.

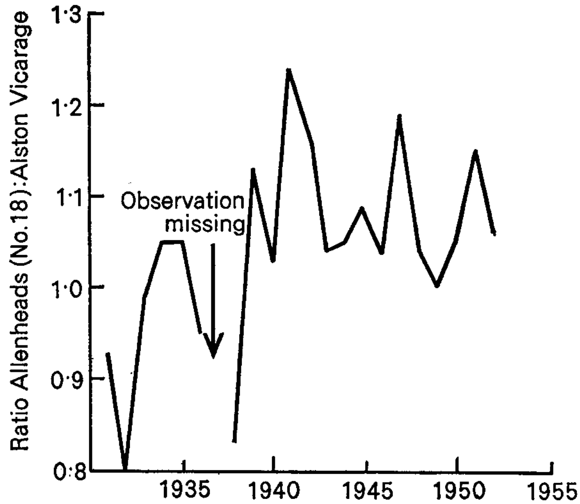

Figure 6. Ratio of annual catches, Allenheads (No. 18): Alston Vicarage. $\bar{x}$ (1931–40) = 0·977, S.D. = 0·110. $\bar{x}$ (1941–52) = 1·090, S.D. = 0·074.

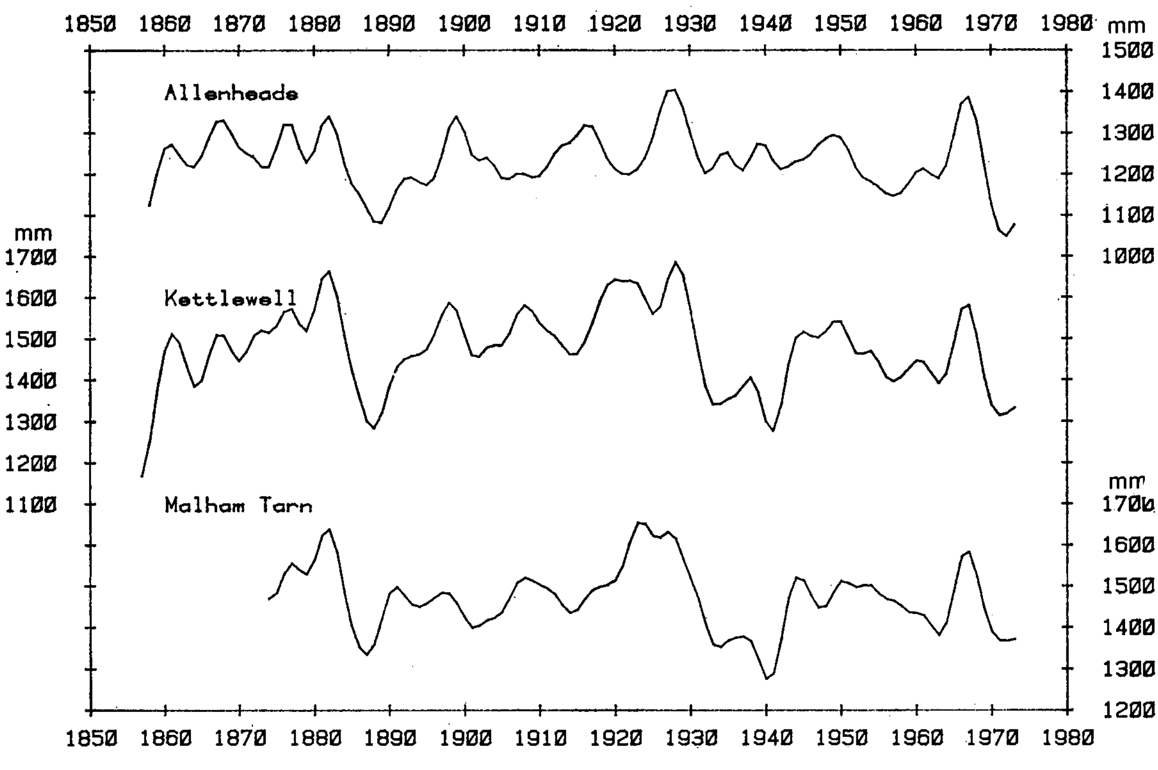

Figure 7. Annual rainfall totals for the three composite records smoothed by a nine weight binomial filter.

Allenheads (Summary)

Period	Station	Factor
1854–79	Allenheads (No. 3)	1·000
1880–93	Haltwhistle Shaft Hall (No. 10)	1·264
1894–98	Haltwhistle Unthank Hall (No. 9)	1·352
1899–1904	Wearhead (No. 13)	0·972
1905–09	Nenthead (No. 15)	0·763
1910–18	Allenheads (No. 18)	1·115
1919	Nenthead (No. 15)	0·763
1920–36	Allenheads (No. 18)	1·115
1937	Alston Vicarage (No. 19)	0·977
1938–40	Allenheads (No. 18)	1·115
1941–70	Allenheads (No. 18)	1·000
1971–72	Alston King Samuel School (No. 20)	1·000
1973–77	Allenheads (No. 18)	1·000

Rainfall recording in Upper Wharfedale and at Malham Tarn

Table II lists all the rain-gauges that have been or are currently operating in the extreme headwaters of Wharfedale and Littondale in the vicinity of Kettlewell and Arncliffe. Also included in the Table are gauges at Malham and Settle in Airedale and Ribblesdale which enable comparisons to be made throughout the period from 1853 to 1977. The location of these gauges can be seen from Fig. 1(b).

Table II. *Rain-gauges in or near Upper Wharfedale*

Gauge No.	Gauge name	First year	Last year	Missing years	Height *metres*	Observer(s)
1	Settle	1837	1870		152	J. Talham
2	Arncliffe	1853	1917		229	Rev. W. Boyd
3	Oughtershaw	1863	1957	1876–84	358	C. H. L. Wood Miss G. J. Wood
4	Arncliffe Anerdale	1890	1909		226	J. Hammond
5	Malham (5 in gauge)	1870	1928		226	various
6	Malham (8 in gauge)	1890	1925		395	various
7	Buckden	1919	1936		244	G. E. Clayton
8	Malham (High Mask)	1929	1950		503	D.I.W.B.*
9	Litton Manor Cottage	1956	1977		250	various
10	Kettlewell	1957	1977		212	Y.W.A.†
11	Malham Tarn	1949	1977		395	C.P.F.S.‡
12	Arncliffe	1971	1976		227	Y.W.A.

* = Docks and Inland Waterways Board, † = Yorkshire Water Authority, ‡ = Council for the Promotion of Field Studies.

Selection of key site

The choice of key site for Upper Wharfedale rests between the rainfall recordings made at Kettlewell (No. 10) and Litton Manor Cottage (No. 9). The latter site was moved in 1972 and was terminated during 1978. Thus the Kettlewell site is the only one available. For Malham Tarn the gauge (No. 18) currently operating will be used as a basis for this composite series.

Construction of the composite record

The earliest record in Upper Wharfedale is that from the village of Arncliffe (No. 2) in Littondale kept by the Rev. William Boyd from 1853 to the early years of the twentieth century and continued until 1917 by the Rev. Canon W. A. Shuffrey. The gauge was sited 50 yards from Arncliffe Church at an unusual height of two feet six inches. The comparison between the Arncliffe record with J. Talham's gauge (No. 1) at Settle in Ribblesdale for the period from 1853 to 1870 reveals two distinct periods in the Arncliffe record which can be corroborated by the record from Kendal in Westmorland (about 20 miles north-west of Arncliffe). The earlier part of the record will therefore need to be increased relative to the latter.

In 1863 Charles H. L. Wood began recording at Oughtershaw Hall (No. 3) in the extreme headwaters of Wharfedale on the Langstrothdale Chase. Mr Wood was the local schoolmaster and he continued recording until 1899 when Miss G. J. Wood, presumably his daughter, continued until the 1940s after which the record was kept by Mr T. White until 1957. Apart from the latter part of the 1870s and the early 1880s the record is complete from 1863 until 1957. For the period from 1896 to 1957 daily rainfall values are available for all the years except parts of 1916. During the 1860s and 1870s it is clear from the 10 year sheets held at the Meteorological Office that Mr Wood also maintained gauges at Oughtershaw School and at Swarthghyll (the source of the River Wharfe). The records from both these sites are, however, fragmentary and not capable of filling in the missing years at the Oughtershaw Hall site. Figs 8, 9 and 10 show comparisons of this gauge record with the Arncliffe (No. 2) record, a gauge at Malham Tarn (No. 5) from 1870 to 1928, and a record from Buckden (No. 7) for the years 1919 to 1936. Further comparison is possible with another record from near Malham Tarn called High Mask (No. 8) for the years 1929 to 1950. All these graphs confirm the validity of the Oughtershaw record throughout the period, except for the later years in the 1880s which are low. The composite record uses the entire Arncliffe record until 1917 after which the Oughtershaw record (No. 3) will be used. The current rainfall site at Kettlewell (No. 10) commenced in 1957 and will be used for the composite record for the period from 1957 to 1977. Fig. 11 shows comparisons between Kettlewell and Litton Manor Cottage (No. 9) for the period 1957 to 1977 confirming both records. The gauge at Litton Manor Cottage was moved in 1972, which explains the peak in that year when some monthly values were estimated.

A comparison between Oughtershaw and the current Malham Tarn record shows good agreement and it was noted that the ratios between Oughtershaw and the Malham Tarn records (No. 5 and No. 8) from 1870 to 1928 and for 1949–57 are remarkably consistent, indicating that the records at Malham Tarn may be homogeneous. Shaw (1956) states that when the rain-gauge was installed by the Council for the Promotion of Field Studies in 1949 the Meteorological Office attempted to position the gauge at very nearly the earlier site. The Oughtershaw : High Mask ratios for 1929–50 indicate a change in that site after 1942. A correction factor for the latter period was calculated. It is therefore possible

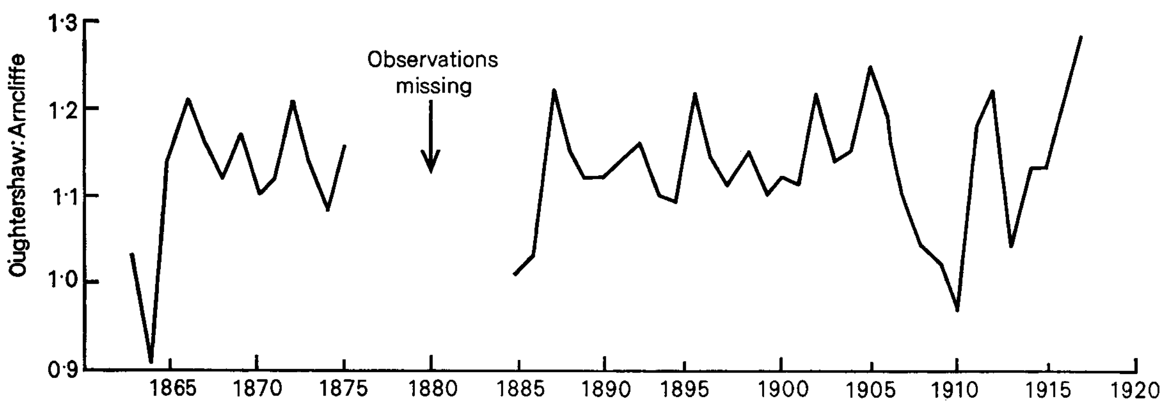

Figure 8. Ratio of annual catches, Oughtershaw : Arncliffe.

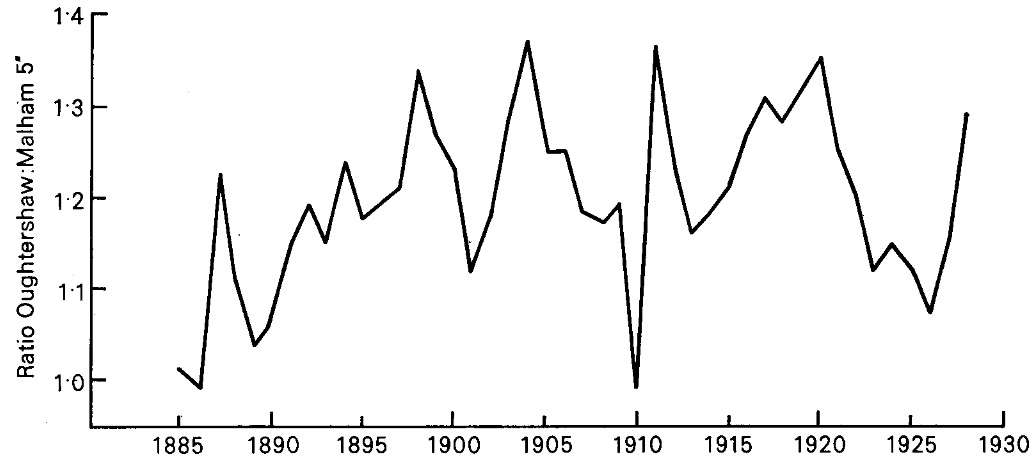

Figure 9. Ratio of annual catches, Oughtershaw: Malham 5 in. $\bar{x}$ (1885–1928) = 1·170, S.D. = 0·077.

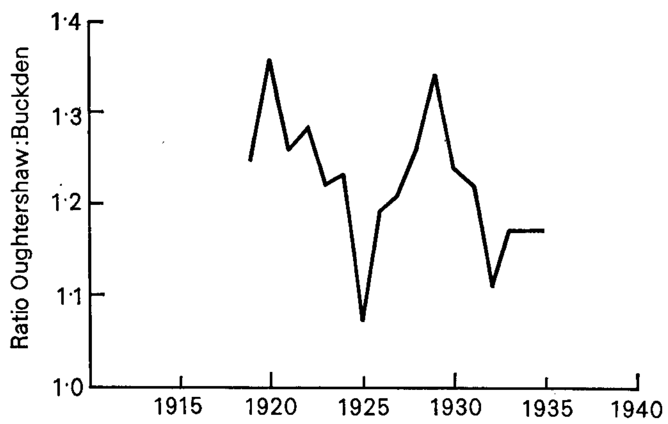

Figure 10. Ratio of annual catches, Oughtershaw: Buckden.

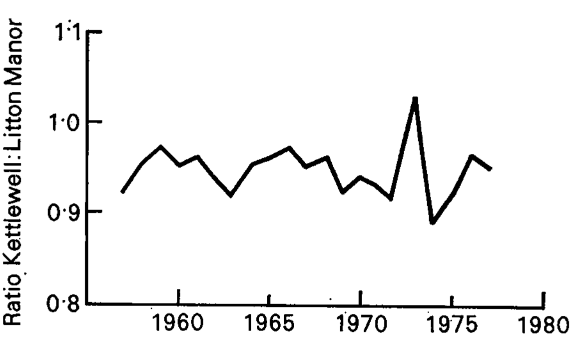

Figure 11. Ratio of annual catches, Kettlewell: Litton Manor. $\bar{x}$ = 0·945, S.D. = 0·029.

to produce a homogeneous record for the years from 1870 to 1977 for Malham Tarn from the three records (Nos 5, 8 and 11) by simply increasing the High Mask record for 1942–48 and treating the rest of the High Mask record and both Malham Tarn records as being for the same site.

The conversion factors for the appropriate gauges in the two composite records (Upper Wharfedale and Malham Tarn) are given here and further details are in Appendix 2 and Appendix 3. Both annual rainfall series, again smoothed by a nine weight binomial filter, are plotted in Fig. 7.

Kettlewell (summary)

Period	Station	Factor
1853–60	Arncliffe (No. 2)	1·127
1861–1917	Arncliffe (No. 2)	0·960
1918–56	Oughtershaw (No. 3)	0·850
1957–	Kettlewell (No. 10)	1·000

Malham Tarn (summary)

Period	Station	Factor
1870–1928	Malham 5 in (No. 5)	1·000
1929–41	High Mask (No. 8)	1·000
1942–48	High Mask (No. 8)	1·170
1949–	Malham Tarn (No. 11)	1·000

Concluding remarks

Annual and monthly rainfall totals have been presented for Allenheads, Kettlewell and Malham Tarn. Monthly values for each series are of course available but would involve pages of tables. Copies of the monthly values for any of the series are available from the author. Copies have also been lodged with the Meteorological Office. Variations in air temperature over the past 40 years have been discussed recently by Manley (1980) with reference to the Nature Conservancy Council's site at Moor House (a site 10 miles south-west of Allenheads and 145 metres higher in the lee of Crossfell, the highest peak in the Pennines).

Further extension of the Allenheads record is possible using the Crewgarth (No. 1) (Table I), Alston (No. 2) (1851–52) and the Allenheads (No. 5) (1837–46) records; however, the lack of sufficient overlap makes this extension difficult. Knowledge of the complete record kept by the Rev. W. Walton at Allenheads from 1837 to 1846 at least, would undoubtedly make this possible. Manley (1980) comments on a record of air temperature kept at Allenheads by Thomas Sopwith from 1857 until 1876. Data for 1836 to 1856 were thought by Manley to exist but he was unable to locate them. It would be interesting to know if a rain-gauge had also been kept at the site.

Further extension of the Kettlewell and Malham series is possible back to 1837 using the Settle (No. 1, Table II) record of J. Talham, a record kept from a gauge at a height of 35 ft above ground, presumably on a roof. Serious discrepancies are apparent during the early part of the Settle record compared with that for Kendal, making the record unreliable. Earlier records in the region are available for Garsdale Head, 15 miles to the north of Oughtershaw, for the period from 1777 to 1779, but these are too short for any practical use.

Acknowledgements

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Appendix 1. Details of the composite rainfall record for the Alston–Allenheads region of Northumberland.

1941–77 *Allenheads.* Conversion factor 1·0 (except 1971–72).

The Allenheads gauge record was terminated in 1971 and recommenced during 1972 at a site 100 yards to the west. The years 1971 and 1972 therefore need to be filled by Alston King Samuel School.

1971–72 *Alston King Samuel School.* Factor 1·0.

The record is only complete for the years 1970–74 and the ratios between this and the Allenheads records for 1970 and 1974 are approximately unity.

1910–40 *Allenheads.* Factor 1·115 (except 1919 and 1937).

Ratio Allenheads : Alston Vicarage (1931–40) = 0·977 (neglecting 1937).

Ratio Allenheads : Alston Vicarage (1941–52) = 1·090.

The factor required to convert to the Allenheads record for 1941 onwards is therefore 1·090/0·977 = 1·115.

1937 *Alston Vicarage.* Factor 0·977.

1919 *Nenthead.* Factor 0·763.

1905–09 *Nenthead.* Factor 0·763.

Ratio Allenheads : Nenthead = 0·684,

therefore to convert to Allenheads for 1941 onwards the required factor is 0·684 × 1·115 = 0·763.

1899–1904 *Wearhead.* Factor 0·972.

Ratio Nenthead : Wearhead = 1·274,

therefore to convert to Allenheads for 1941 onwards the required factor is 1·274 × 0·763 = 0·972.

1894-98 *Haltwhistle Unthank Hall.* Factor 1·352.

Ratio Allenheads : Unthank Hall (1869–79) = 1·352.

1880–93 *Haltwhistle Shaft Hall.* Factor 1·264.

Ratio Shaft : Unthank (1879–93) = 1·070,

therefore to convert to Allenheads for 1941 onwards the required factor is 1·352/1·070 = 1·264.

1854–79 *Allenheads (earlier records).* Factor 1·00.

Ratio Hallington : Allenheads (1910–77 neglecting 1937, 1971–72 and correcting the earlier period (1910–40)) = 0·59.

Ratio Hallington : Allenheads (earlier 1862–79) = 0·594,

therefore Allenheads records are compatible.

The Hallington reservoir site is a continuous record kept from 1862 approximately 20 mile north-east of Allenheads and is the nearest record that covers all the years of both records.

Appendix 2. Details of the composite rainfall record for Upper Wharfedale

1957–77 *Kettlewell* × 1·0.
1918–56 *Oughtershaw*. Conversion factor 0·850.
Ratio Oughtershaw : Malham Tarn (1949–57) = 1·157.
Ratio Malham Tarn : Kettlewell (1957–77) = 1·017,
therefore ratio Kettlewell : Oughtershaw = 1/(1·017 × 1·157) = 0·850.
1861–1917 *Arncliffe*. Factor 0·960.
Ratio Oughtershaw : Arncliffe (1885–1917) = 1·129, S.D. = 0·076,
therefore to convert to Kettlewell multiply by 1·129 × 0·850 = 0·960.
1853–60 *Arncliffe*. Factor 1·127.
Ratio Settle : Arncliffe (1861–69) = 0·689.
Ratio Settle : Arncliffe (1854–60) = 0·809,
therefore to convert early Arncliffe records multiply by 0·809/0·689 = 1·174,
therefore to convert to Kettlewell multiply by 0·960 × 1·174 = 1·127.

Appendix 3. Details of the composite rainfall record for Malham Tarn

1949–77 *Malham Tarn* × 1·0.
Ratio Oughtershaw : Malham Tarn (1949–57) = 1·157, S.D. = 0·079.
1942–48 *High Mask*. Conversion factor 1·170.
Ratio Oughtershaw : High Mask (1942–50) = 1·385, S.D. = 0·077,
therefore to convert to Malham Tarn multiply by 1·385/1·157 = 1·170.
1929–41 *High Mask*. Factor 1·0.
Ratio Oughtershaw : High Mask (1929–41) = 1·184, S.D. = 0·085.
Factor of unity used owing to the similarity of the ratios of the Malham gauges with Oughtershaw.
1870–1928 *Malham 5 in*. Factor 1·0.
Ratio Oughtershaw : Malham 5 in (1885–1928) = 1·170, S.D. = 0·077,
Factor of unity used owing to the similarity of the ratios of the Malham gauges with Oughtershaw.

551.508.21: 681.2.08

Routine calibration of solar radiation instruments

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Summary

The article describes the solar radiation work within the Test Laboratory section of the Operational Instrumentation Branch of the Meteorological Office and its relationship to the Meteorological Office National Radiation Centre. The equipment and methods used for the calibration of pyranometers and net pyrradiometers, and a system for the determination of the cosine response of pyranometers to varying angles of incident radiation in the laboratory are described.

1. Introduction

Collingbourne (1969) described the early history and the current practice of the solar radiation measurement and calibration organization within the United Kingdom. He referred mainly to the National Radiation Centre which at that time was based in the Meteorological Office Observatory at Kew.

In January 1974 the responsibility for (a) the calibration and development of operational instrumentation, and (b) the maintenance of radiation standards and the operation of the United Kingdom network of observing stations, was transferred from Kew to the Meteorological Office experimental site at Beaufort Park, Easthampstead. At the same time the functions of (a) and (b) were devolved to two branches, Operational Instrumentation (Met O 16) and Observational Requirements and Practices (Met O 1) respectively. Although these functions are, of necessity, related, this article is concerned mainly with (a) which is undertaken by the Test Laboratory section of the Operational Instrumentation Branch.

2. Standards and traceability

The National Radiation Centre (NRC), now based at Beaufort Park, maintains the UK national standards for solar radiation and houses the reference instruments. These are Ångström pyrheliometers (see Plate I). Two transfer standard instruments, held in the Test Laboratory for use in routine calibrations, are compared twice a year with these standard instruments. The transfer standards used are a Linke–Feussner pyrheliometer* (see Plate II) and a Kipp and Zonen pyranometer*. May (1980) describes previous and current practice in the maintenance of radiation standards by the Meteorological Office.

3. Measurement systems

During the calibration of radiation sensors voltages between about 0·2 and 10 mV are usually encountered. It is also necessary to monitor continuously three or more pyranometers simultaneously to determine their mean output voltages over a specific period.

When the calibration laboratory was set up at Beaufort Park in 1974 the opportunity was taken to improve the measurement facilities previously used at Kew. A console was constructed housing all the power supply units and a Leeds and Northrup 12-channel chart recorder. Arrangements were made to suit the different instruments being calibrated.

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* Pyranometers are a class of instrument used to measure global and diffuse solar radiation. The Kipp and Zonen instruments are commonly referred to by the manufacturer's name 'Solarimeter', which has no accepted definition. Similarly the Linke–Feussner pyrheliometer is commonly referred to as an actinometer.

This system was modified and augmented a number of times, and in 1978 a full investigation of the accuracies of voltage measurement was carried out. The results showed that uncertainties varied between ±0·25% for voltages up to 1 mV and ±3·0% for voltages above 1 mV. Further errors were being introduced into the calibrations owing to visual estimations of the chart trace by the operator, and also owing to small variations in the accuracy of the calibration of the transfer standard instruments compared with the standards held in the NRC.

To reduce these uncertainties a new system for voltage measurement was acquired and put into service in mid-1979. The system acquired, illustrated in Plate III, consists of a digital voltmeter (DVM) (1) and multi-channel scanner (2), a printer (3), and a Commodore PET microcomputer (4). The DVM has an uncertainty of ±1 μV over the range of voltages encountered in radiation calibration. Programs were supplied with the system to cover both pyranometer and net pyrradiometer calibrations.

The equipment is based on the interface 'bus' system originally published by the Institute of Electrical and Electronic Engineers (1975) but with subsequent modifications (1978). This interface bus system is now becoming accepted, under various guises, as the standard for automatic test equipment (ATE). Under this system up to 15 suitably interfaced devices can be connected together to produce ATE capable of meeting most individual needs. At the heart of each ATE is the controller, a programmable microcomputer, which will direct, via the program, the various measuring and display devices, store and use the data produced, and display any results.

4. Calibration of pyranometers

In 1966 a spherical integrating chamber was installed in the laboratory at Kew. This enabled pyranometers to be calibrated more quickly and conveniently indoors. The chamber was based on a design suggested by Latimer (1964). Principally because of its physical size and the need for air to be drawn into the chamber from outside, it was decided against moving it to Beaufort Park where, instead, a new chamber was designed and built within the Operational Instrumentation Branch.

The current layout of this new chamber which differs in a number of ways from the Kew model is illustrated in Fig. 1. Instead of consisting of two large hemispherical mouldings the new chamber was made up from six sections (1), which can be easily dismantled and moved elsewhere. Because the original site at Beaufort Park was in a laboratory with no external walls, no direct inflow of cool outside air was possible. Vents (2) were therefore placed near the base of the chamber to admit air from an air-conditioned laboratory, the air then being removed through the top of the chamber (3) by an extractor fan. Light from six 600 W tungsten–halogen lamps (4), similar to those used in the Kew chamber, is reflected off the white interior surface of the chamber providing an even, steady source of radiation. The irradiances within the chambers at Kew and Beaufort Park have been shown to be very similar. However, it was found that the temperatures of the sensors and of the interior of the new chamber would vary from about 30 °C up to about 50 °C, especially during long calibration sessions. Eventually, during a reorganization of laboratories within Beaufort Park in mid-1979, an air-conditioner unit (5) and an electrical heater (6) were fitted into the side of the chamber. A portion (7) of the incoming cold air is directed over the heater and up the central column to the underside of the sensors, while the remainder (8) enters the main body of the chamber. With the air-conditioner running continuously and the heater thermostatically controlled, the temperature of the test sensors is held at 22 °C±0·2 °C while the chamber temperature, being more dependent on the external laboratory condition, will rise after an hour to about 26 °C. The sensors (9), one transfer standard and two under test, are mounted below a shade plate (10) which allows only the glass hemispheres and thermopile surfaces to be exposed. The mounting plate is linked to the shaft of a motor (11) and can be rotated

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Plate I. Ångström pyrheliometer.

Plate II. Linke–Feussner pyrheliometer.

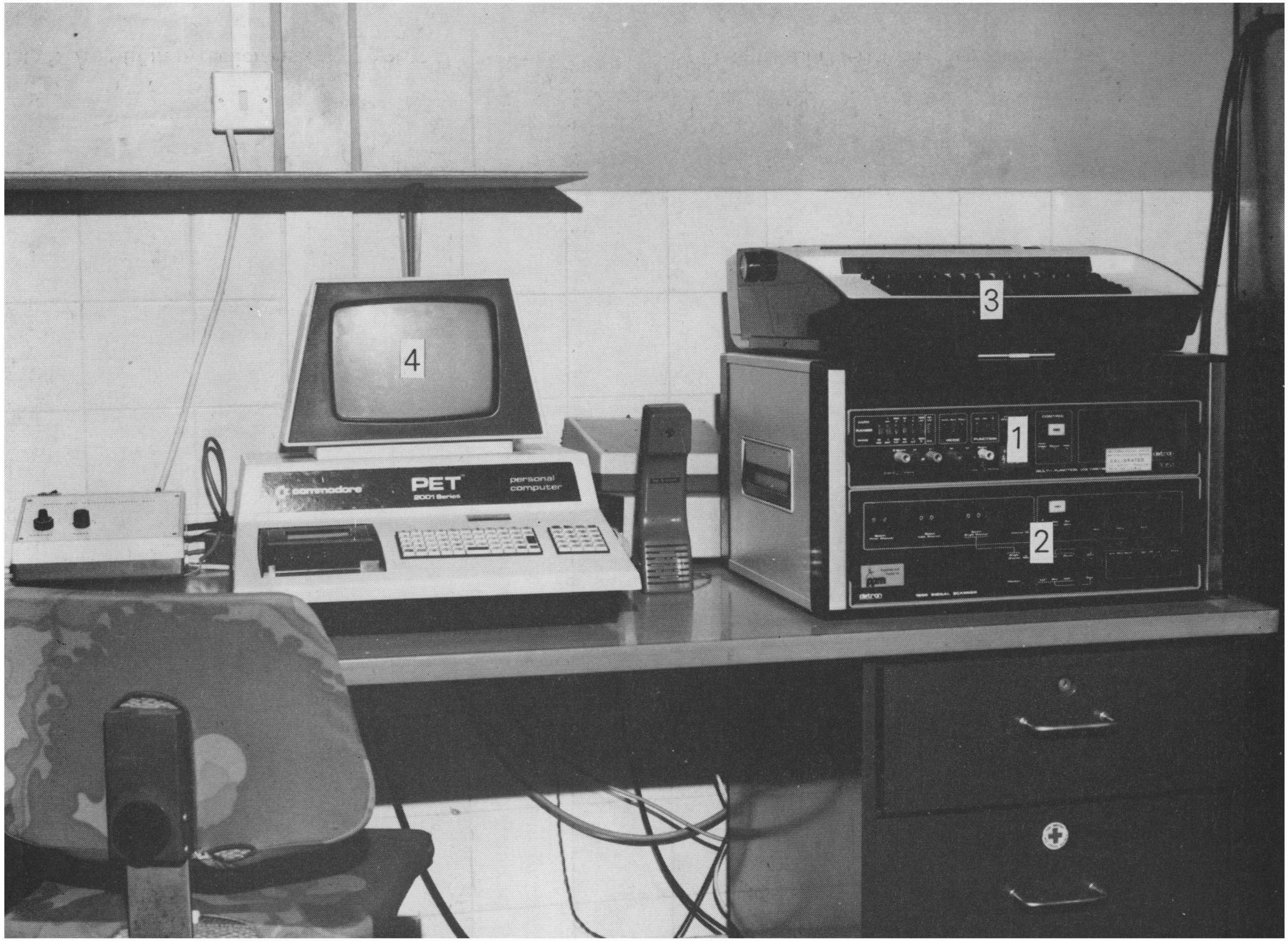

Plate III. Radiation calibration measurement system.

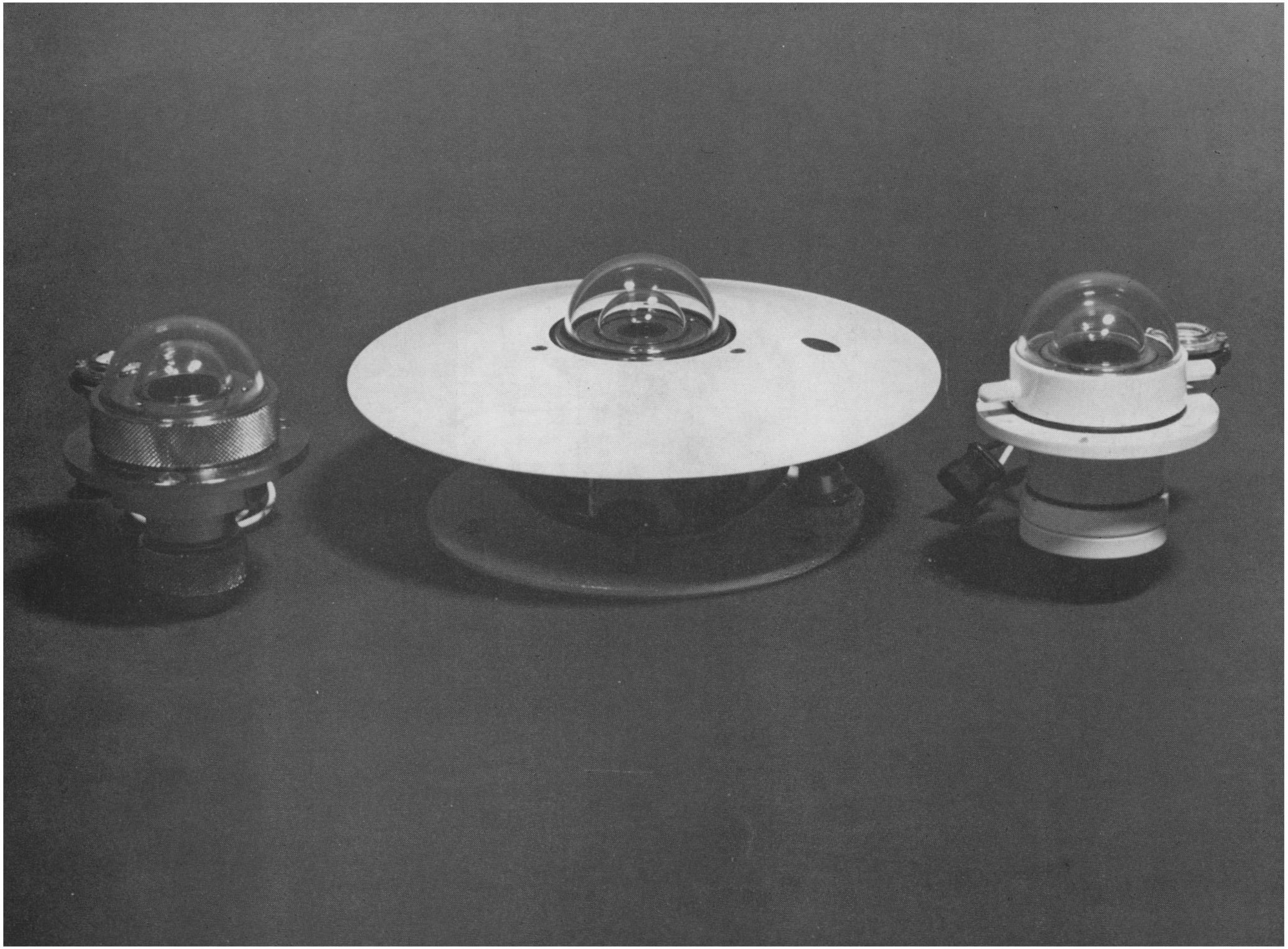

Plate IV. Pyranometers. Left to right: Kipp and Zonen CM5, Eppley precision spectral pyranometer, Kipp and Zonen CM2.

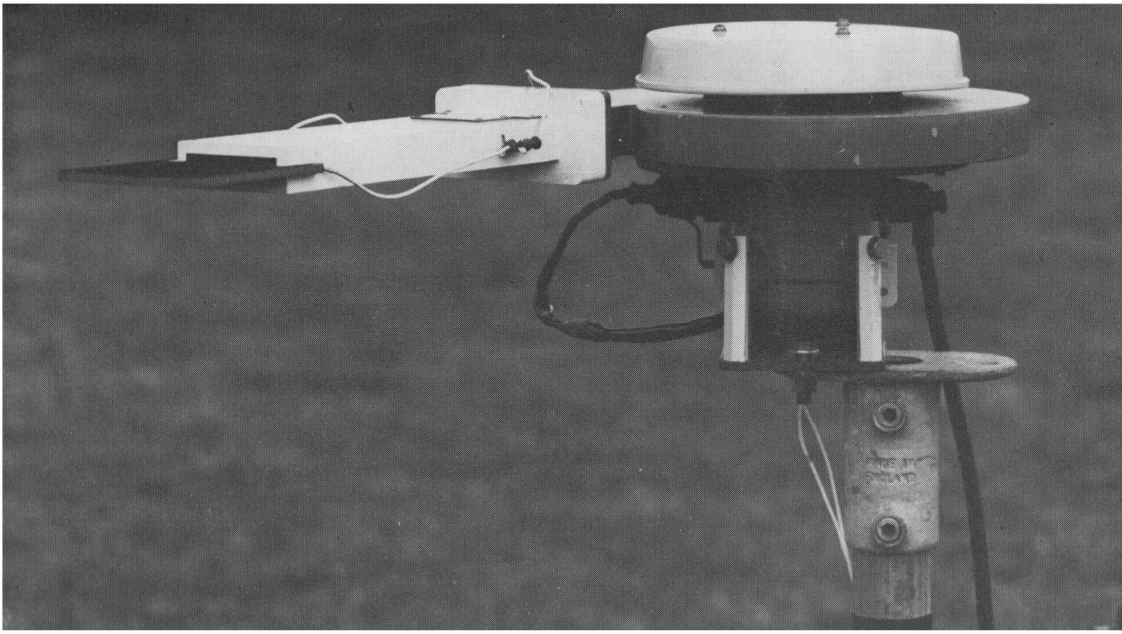

Plate V. Meteorological Office pattern net pyrradiometer.

Plate VI. Funk-pattern net pyrradiometer.

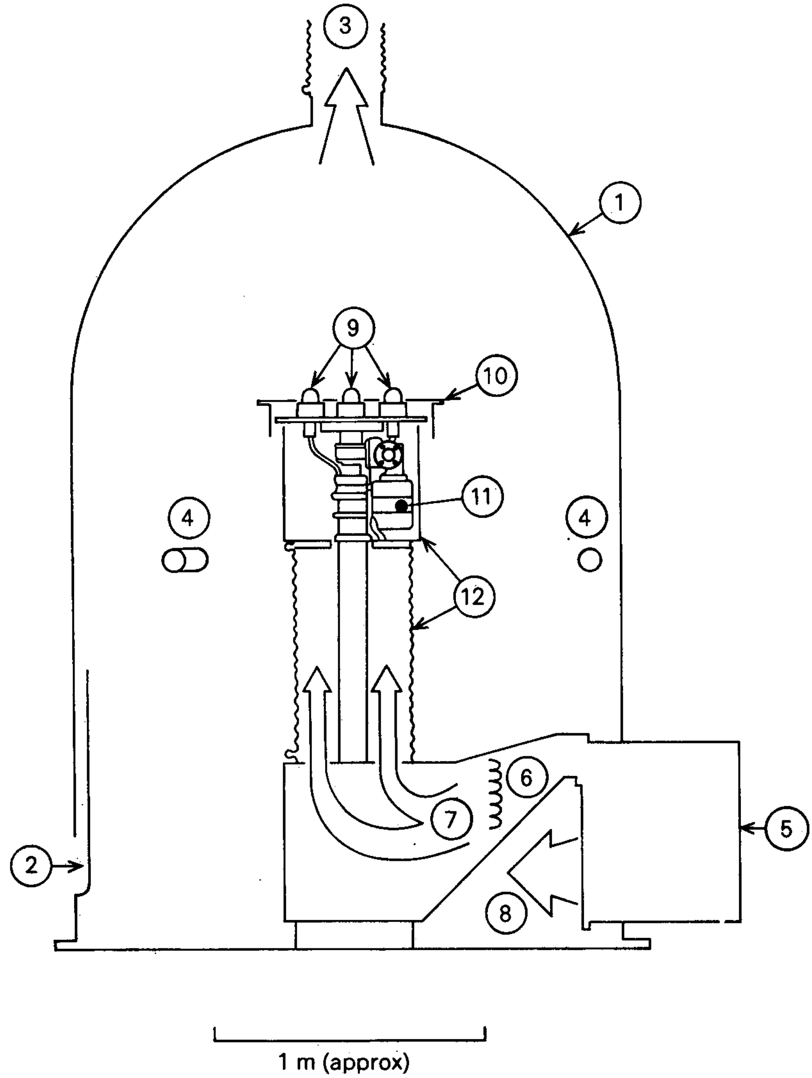

Figure 1. Pyranometer calibration chamber. A table carrying a transfer standard pyranometer and two pyranometers under test, rotating in a field of uniform irradiance.

through 360° in either a clockwise or an anticlockwise direction; one revolution in either direction takes 10 minutes. The whole mechanism is enclosed within a shield (12) to prevent the bases of the sensors and motor becoming heated.

A normal calibration is carried out by comparison of the output of the transfer standard with the two pyranometers under test. The instruments are revolved once in each direction in the chamber to take account of any slight inhomogeneity of the radiation source. During the test period of about 20 minutes the PET microcomputer directs the DVM to take readings of the outputs of each sensor at intervals decided by the operator, usually every 10 seconds for Kipp and Zonen pyranometers. All the readings are stored and, at the end of the run, mean voltages are calculated and then, from the known sensitivity of the transfer standard instrument, the sensitivities of the test instruments are computed. A certificate of calibration for each of these instruments is automatically produced on a printer.

Although, at present, pyranometers can only be calibrated in the chamber, it will be possible to calibrate them outdoors, if necessary, when suitable mounts and connecting cables have been installed. This facility should be available at Beaufort Park in a year or so.

The types of pyranometer which can be calibrated using this system are:

(a) Kipp and Zonen pyranometers, models CM2 and CM5, these being the main instruments used by the Meteorological Office and many outside authorities, and

(b) Eppley precision spectral pyranometers, used by the Meteorological Office for specialized purposes requiring more accurate measurements.

Examples of these instruments are shown in Plate IV.

5. Calibration of net pyrradiometers

The calibration of net pyrradiometers both in the laboratory and field at Kew was described in detail by MacDowall (1955). At that time the method of short-wave calibration consisted of shining a tungsten 2000 W lamp upon the sensor plate, held between two large plates of glass in an attempt to reduce the excess long-wave radiation emanating from the lamp housing. It was later thought, however, that these glass plates became heated by radiation from the lamp, and then re-radiated long-wave radiation to the sensor. The Kew system also had the lamp and net pyrradiometer mounted in a horizontal plane and this was believed to have an effect on the sensitivities of the instruments, especially the enclosed sensor types, owing to differences in the internal convection currents.

In view of these shortcomings in the Kew laboratory calibration system a new one was designed and built within the Operational Instrumentation Branch at Beaufort Park in 1974. A frame mounted on a bench in a darkroom holds a 600 W tungsten–halogen lamp shining vertically down on the sensor plate 1·5 metres below. As the radiant flux of the lamp is rather low, some attempt has been made to amplify the beam by incorporating two silvered prisms in the lamp housing. Even so, the irradiance is still only about 5 mW cm^{-2} at the sensor position. An extractor fan in the lamp housing removes excess heat to the outside. At regular intervals a shade plate is automatically interposed midway between the lamp and the sensor. In this way the sensor is alternately exposed to and shielded from the short-wave radiation from the lamp, for periods of five minutes in each state. As the long-wave radiation reaching the sensor is essentially the same for both positions of the shade plate, the difference between the two readings of the sensor represents the radiant flux of the lamp.

Before any calibration of a net pyrradiometer takes place the output of the lamp is accurately determined by placing the Linke–Feussner pyrheliometer transfer standard in the position to be occupied by the test sensor.

The net pyrradiometer under test is next mounted and levelled in a precise position beneath the lamp. A calibrated marker enables the instrument to be positioned at the correct distance from the two adjacent walls and from the floor. The actual test consists of monitoring the output of the sensor with the microcomputer programmed to distinguish between the 'unshaded' and 'shaded' modes and then to compute the mean value of the readings taken during four 'unshaded' and three 'shaded' periods. Quality control routines in the program ensure that the spurious readings encountered during the changeover from 'unshaded' to 'shaded', and vice versa, are eliminated from any calculations. The difference between the 'unshaded' and 'shaded' readings is determined and the sensitivity of one side of the sensor plate is calculated, using the lamp output factor previously measured. The sensor plate is then inverted and repositioned and the whole calibration sequence repeated. At the end of this sequence the final sensitivity is computed as the mean of the sensitivities of both sides of the sensor plate. A certificate of calibration is then produced automatically on the printer.

Net pyrradiometers must have symmetrical plates, i.e. the sensitivites of both sides of the plates must agree within 2%. To take acount of any deterioration of the sensor during exposure in the field the instrument is calibrated before any necessary refurbishing takes place prior to a final calibration and re-issue.

For many years the black paint used for coating the sensor plates was Parsons Optical Black whose properties had been investigated by the National Physical Laboratory and described in more detail by MacDowall (1955). Supplies of this paint became increasingly difficult to obtain. Also the surfaces produced with it were not very durable. At each return from an outstation the plates needed to be cleaned and repainted. The application of this paint was a difficult task when the requirement was to produce a coating which had to have equal absorption of radiation on both sides of the sensor. The process often resulted in asymmetric sensitivities and had to be repeated.

After extensive comparison trials at Beaufort Park in 1978 a new paint was introduced for use on net pyrradiometer plates. This was 'Nextel' Velvet Coating 101-C10 produced by 3M. The manufacturer's claimed performance for this paint indicates that the reflectance for radiation of wavelengths between 0·7 and 1·1 μm is 1·5% and between 2 and 35 μm is 1·0%. In field trials at Beaufort Park no appreciable difference in sensitivity was noted between Parsons paint and 3M's Nextel. However, the 3M's paint was found to be much more durable and easier to apply. It is now no longer necessary to repaint plates every time an instrument is returned for routine calibration. The plates are carefully washed and the sensitivities are found to have altered little from the original calibration, provided no other damage to the surface has occurred.

The main instruments calibrated under this system are the standard Meteorological Office pattern net pyrradiometer with the open ventilated sensor plate, (see Plate V) and enclosed sensor types based on the pattern designed and described by Funk (1959) (see Plate VI). These are mainly being used by universities and some other government departments.

6. Determination of cosine response

The output of a pyranometer varies theoretically as the cosine of the zenith angle of the incident light. Ideally pyranometers should obey this cosine law with no deviation but unfortunately they do not.

In the 1960s an apparatus was built at Kew to determine such deviations of response for any particular pyranometer and this was described briefly by Collingbourne (1969). Although this apparatus was brought to Beaufort Park, certain drawbacks were encountered, particularly in the uniformity of the light beam. Also the sequence of operations necessary to determine the cosine response of a single pyranometer was both long and labour-intensive. With these shortcomings in mind the Operational Instrumentation Branch began to develop an improved, automated version of the Kew apparatus.

Although it is not yet fully developed, a new apparatus has been built and it is hoped it will be operating in the near future. The basic layout of the new machine (Fig. 2) follows that of the Kew model in that a fixed light source (1) is directed via mirrors (2) and (3) mounted on a movable arm on to a rotatable table (4) holding the test sensor (5). For clarity, the arm is not shown on the diagram. Thus, by moving the arm and rotating the table, light can be made to fall upon the sensor from any angle of azimuth and elevation. The arm and the table are driven by servo systems (6) and (7) incorporating photoelectric sensors and sector discs. By this means it is possible to set the arm at certain

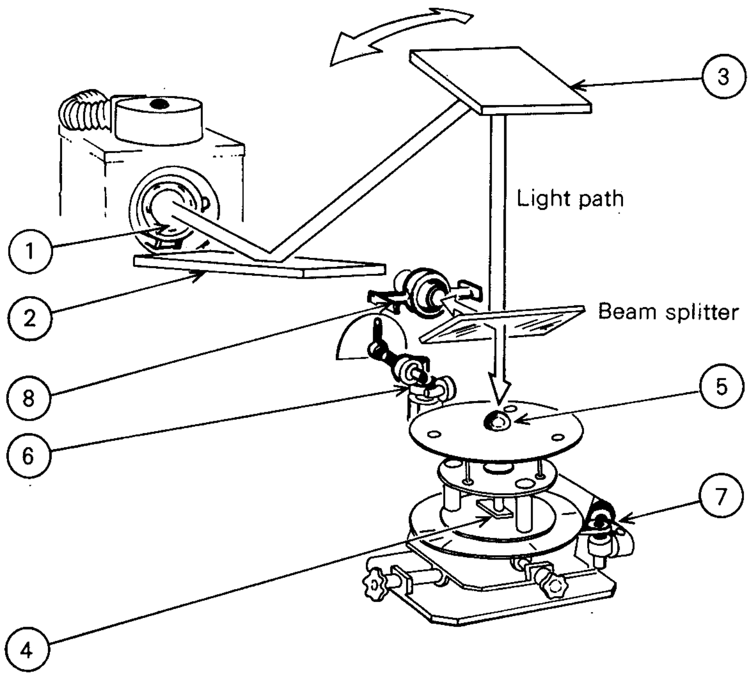

Figure 2. Pyranometer 'cosine response' apparatus. Apparatus for directing a stable, uniform beam of light on to a pyranometer from precise angles of incidence and azimuth.

standard angles of elevation to within 3 minutes of arc, and the table to within 2 degrees, the latter being sufficient for our needs. Control circuitry has been designed for the servo motors, so that the whole sequence of cosine response testing can be operated by the automatic measurement system.

When the system is used operationally, pyranometers will have routine tests carried out which will determine the deviation of response from the ideal at every 30° of azimuth at zenith angles of 30°, 45°, 60°, 70°, 75° and 80°. Standard pyranometers will have tests carried out at the same zenith angles but at 10° azimuth intervals. The complete automatic calibration sequence will take about 9 hours for a routine test and 11 hours for a standard pyranometer test. At the end of tests, again, a certificate will be printed out.

Although the electrical and mechanical systems work well, problems have arisen concerning the stability of output of the lamp. The intensity of the light output of the lamp is controlled by varying the applied voltage in response to variations in intensity detected at (8). A 1000 W compact-source iodide discharge lamp was obtained, which has a spectral distribution similar to that of the sun. A series of tests was carried out with the machine positioned so that the beam of light was directed vertically down on to the pyranometer, that is in the zenith position. A linear interpolation between two readings from the pyranometer taken at the zenith, one hour apart, showed that the intermediate reading gave errors which rarely exceeded 0·3%. However, a further series of readings taken with the lamp beam at 80° from the zenith (i.e. 10° above the horizontal) gave an average output which varied by as much as 7%. The greatest errors were experienced when the lamp was switched off and then on again.

It is suspected that these errors are caused by shifting of the lamp arc. As it is to be expected that all discharge lamps will give rise to similar errors, it has been decided to obtain a tungsten–halogen lamp. It is hoped that this, although not having the correct colour temperature (3200 K as opposed to 5400 K), will be inherently more stable than the compact-source iodide lamp.

7. Future developments

The systems at present in use are under constant review with particular emphasis on the need for suitable transfer standard instruments. Also under active consideration is equipment to determine operationally the temperature coefficient and linearity of response of pyranometers.

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551.509.58: 69

Weather forecasting for construction sites

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Summary

Many types of forecast benefit from the forecaster having some awareness of the use to which his advice is put and this is particularly so in respect of forecasting for building and civil engineering sites. The purpose of this paper is to assist forecasters who provide such services; parts of it should also prove helpful in enquiry bureaux when providing climatological data to the building industry.

Weather forecasts and site management

Bad weather during the early stages of a building contract can cause delays for which no amount of good weather later on can compensate; at later stages there is more concern with inside work which is much less prone to interruption by the weather. On the other hand, most civil engineering projects are open to the elements at all times, so that the adverse effects of bad weather can remain much the same throughout. The contractor can fairly claim for the contract period to be extended when bad weather has caused long delays but this is in the hope of reducing his losses rather than recouping them entirely; bad weather means a financial handicap for the contractor as well as for his client.

In recent years building operations have been made less weather-sensitive by means of protection while work proceeds (e.g. enclosure within plastic sheeting), use of additives (e.g. antifreeze in concrete and mortar) and the protection of completed work that is liable to damage. However, shrinking profit margins have meant that every item that costs money has had to be re-examined on a cost–benefit basis and as protective measures can be expensive firms do not want to take them unnecessarily. A report commissioned by the Construction Industry Research and Information Association (Smith and Rawlings 1974) showed that forecasts prepared specifically for building operations, combined with regular discussions between site manager and forecaster, were a useful tool for technical management. While the results of this informed dialogue were seldom spectacular, the operational advantages which accrued over a period of several months were carefully quantified and showed that the scheme was nearly always cost-effective, a benefit: cost ratio as high as 10:1 being noted in some cases. The report concluded that the main uses of weather forecast information are in (a) the prevention of damage, (b) aiding work relocation decisions and (c) day-to-day operational planning.

Many firms already use the free public weather forecast service as a tool in the control of work but, up to now, relatively few firms have paid for forecasts and warnings tailored specifically to the operating limits of individual projects. The potential exists for a much greater demand for the benefits of construction-weather forecasts.

Because of the development of improved techniques construction processes have become more complex and, in consequence, there are now many firms which specialize in a limited range of work. In many cases this narrows their individual weather interests to such an extent that a forecaster concentrating upon specific weather elements can provide valuable assistance in the short-term planning of operations. For the main contractor, however, the important criteria at any particular time are the practical operating limits for the work in hand, so the emphasis will change as the work progresses, sometimes even from one day to the next, and a routine forecast in standard form may well be inappropriate. If the site manager has regular contact with a particular team of forecasters then both sides can achieve some understanding of the relationship of the current pattern of work to the weather prospects. As is so often the case when seeking meteorological advice it is sometimes more difficult to get the question right than to get the forecast right. Optimum results are most likely to be achieved through the flexible approach offered by a consultancy-type service.

Operating limits

A RILEM report (1965) and Lacy (1977) described the effects of weather on construction processes and explained how more than one weather element can hold up a particular activity. The weather can hinder work either because it will lead to an unsatisfactory end-product or because it is affecting the efficiency or safety of the people involved. Table I lists 'stop work' criteria for various operations; some of these values are based on subjective estimates and are therefore uncertain but, wherever possible, the criterion quoted has been obtained by reference to a code of practice or construction industry publication (the suffixes shown in Table I relate to these references). For some of the operations, additional considerations pertain which could not be included in Table I conveniently and these are set out below.

Excavation and earth moving. These are essentially spring, summer and autumn activities which can be adversely affected by wet weather. During and after rainfall, although the contractor may take some form of remedial action, the effect on work largely depends on how quickly the additional moisture can be either absorbed by the soil or removed by evaporation; these processes, in turn, depend on the surface conditions and soil properties (e.g. soil moisture deficit), as well as the weather.

Concreting. Drying winds can lead to the cracking of large areas of unprotected concrete and this is thought to be due to drying shrinkage of the surface layer. Wind conditions therefore need to be considered in conjunction with air temperatures when contractors are assessing the need for protective measures. However, the minimum temperatures quoted in Table I will not apply if heated concrete or antifreeze admixtures are used.

Roads: asphalting. During rolling, asphalt needs to remain above a temperature within the range 80–120 °C, according to type, so strong, cold winds can present problems because they can cause premature cooling and thus inhibit compaction.

Roads: surface dressing. Apart from the low temperature thresholds given in Table I, high temperatures can also be a problem because the bitumen can be too liquid for the stone chippings to adhere properly; the limiting weather conditions are those likely to lead to a road surface temperature of 35 °C or more.

External painting and joint sealing. These processes cannot be done on surfaces which are moist, and materials such as steel and masonry may become moistened by condensation when the air becomes markedly warmer and more humid. A forecast of such a change could help a contractor to decide to defer operations or take precautions.

The imprecise nature not only of the weather but also of the various construction processes will, of course, lead to some differences from the values quoted in Table I. Moreover, the working method being used may modify the 'stop work' point.

Some operations are not themselves directly affected by bad weather; rather it is the discomfort of the people involved that decides the weather limits. For example, some outdoor jobs may be stopped when it is raining merely because it is too unpleasant to continue working. The point at which work will stop may well also depend on temperature or wind speed, or a combination of the two.

Forecast content

(a) *Working day*

Apart from the demands of human safety, the contractor's principal concern with the weather is the extent to which work may be delayed with resulting disruption to the program for the completion

Table I. *Weather inimical to construction operations*

	Rainfall intensity	Snow	Wind gusts exceeding *knots**	Air temperature *degrees Celsius*	Other factors
Surveying and setting out	Slight or more[1] (but not 'very slight')	Falling[1]	35[1]	—	Hard frozen ground (for peg driving). Fog
Excavation and earth moving†	Prolonged moderate/heavy[1]	Falling/lying[1]	—	Severe frost	Hard frozen ground. Drying conditions. Dense fog[1]
Concreting†	'Slight to moderate' or more[2]	Falling/lying[2]	—	< +2 when falling[3] < +1 when rising[3]	Sub-surface frozen or flooded—roads. Frost on reinforcement or shuttering—casting
Roads: asphalting†	Slight or more (but not 'very slight')[4]	Falling/lying[4]	—	<0 when falling, < −1 when rising } recipe mixes[4] <8 designed mixes[5]	Sub-surface wet or frozen[4] <2 °C surface temperature—recipe mixes[5] <5 °C surface temperature—designed mixes[5]
Roads: surface dressing†	Slight or more (but not 'very slight')[6]	Falling/lying[6]	—	<15 stone chippings[6] <8 using hot binder <5 using emulsion	Sub-surface wet or frozen[6]
Sheet steel piling	Moderate or more[1]	—	35[1]	—	—
Steel frame erection	Any intensity	Falling/lying[1]	20[1]	—	Frost or ice on frame members. Dense fog[1]
Welding	Slight or more (but not 'very slight')	Falling/lying	30	—	Very cold members, especially when large
Scaffolding	Slight or more (but not 'very slight')	Falling/lying	30	—	Frost or ice on members
Cradles	Heavy	Heavy snow falling	25	—	Task may dictate criteria
Tower cranes	—	Heavy snow falling	40 at jib height[7]	—	Dense fog on ground or at jib height

Table I.—*continued*

Craning lightweight panels	—	Heavy snow falling	25 at load height[8]	—	Dense fog on ground or at load height
Bricklaying	Slight or more (but not 'very slight')	Falling/lying	30[1]	<2 when falling[3] <1 when rising[3]	Frost on building surfaces
Roofs: slating and tiling	'Slight to moderate' or more	Falling/lying	30	—	—
Roofs: asphalting	Slight or more (but not 'very slight')	Falling/lying	25	<7[1]	Sub-surface wet, frosty or icy[9]
Roofs: built-up felt	Any intensity	Falling/lying	25	<1	Sub-surface wet, frosty or icy
Roofs: sheeting (e.g. corrugated asbestos)	Slight or more (but not 'very slight')	Falling/lying	25	—	—
Rendering	Slight or more (but not 'very slight')	Lying	35	<3 when falling <2 when rising	—
External painting† and joint sealing	Any intensity[10]	Falling[10]	25 (painting only)	<4 or >32	Moisture on surfaces[10] Relative humidity >90%
Glazing	Any intensity[1]	Falling[1]	25[1]	—	Surfaces wet or frozen
Materials: storage or access to	Moderate/heavy	Lying	—	Severe frost	Frost following >5 mm rain (bricks)
Partially completed structures: damage risk	Prolonged moderate/heavy	Substantial snow depth	40	Moderate/severe frost	Large hail. Sudden temperature changes

Notes. † Special considerations for these processes are described in the text.
* Some users would be more familiar with speeds expressed in miles per hour, metres per second or Beaufort force.
The superscripts shown relate to the references, given at the end of this paper, which were used to obtain the criteria quoted. 1. Russo 1971, 2. Pink 1978, 3. Smith and Rawlings 1974, 4. British Standards Institution (BSI) 1973a, 5. Department of Transport 1979, 6. Department of the Environment 1972, 7. BSI 1977, 8. Lacy 1977, 9. BSI 1973b, 10. BSI 1966.

of the various stages of the contract. Timing is an essential element in weather forecasting for contractors who need to know the likely starting time and duration of weather that is prohibitive for particular processes or for work in general. The most useful prohibitive values are probably:

Rain

(1) Any rain

(2) 'Slight to moderate' rain or slight showers (about 0·5 mm h^{-1}), or more

(3) Moderate rain or 'slight to moderate' showers (about 2·0 mm h^{-1}), or more

(4) A fall of 10 mm or more in 24 hours (ground very wet or flooded).

Temperature. Less than 2 °C.

Wind

(1) Gusts over 20 knots

(2) Gusts over 30 knots.

Snow. Falling or lying.

Even using descriptive terms for precipitation the forecast can be worded to give a clear indication of the likely loss of time on outdoor work. For example, a forecast of 'frequent showers developing by the afternoon' may mean that only the morning will be suitable for work, whereas 'occasional mainly light showers' gives hope for a full day's output. The description of rainfall intensity uses words in their ordinary sense so as to avoid misunderstanding, and yet has to be related to what different jobs can tolerate. Terms such as 'very slight' or 'moderate, sometimes heavy' may be useful. If it is raining when work should start then a contractor will often wait until he is sure that a clearance has arrived before committing his resources. Light drizzle in a warm sector may prevent work from starting merely because it looks like a threat of worse to come. A clearance as late as mid-afternoon usually means that little can be done in the rest of the day; wet surfaces may have to dry off first, and work may be hindered if the ground is wet or muddy.

The actual working day is usually limited to daylight hours so there is often some restriction in winter and especially if there is thick cloud cover. If particularly poor light is expected some mention of this could be made in a forecast.

(b) *Overnight and beyond*

The prevention of damage to many types of newly completed work may require action by the contractor before the end of the working day. Particularly important are the prevention of frost damage to concrete and mortar, the protection of partially completed walls from wind damage and the avoidance of damage due to flooding. The most useful warnings will usually be:

Temperature. Moderate or severe frost.

Wind. Gusts over 40 knots.

Rain. Prolonged periods of heavy rain.

To allow time to arrange any necessary protection a forecast for the following night is required by 1600 local time at the latest. Before a weekend the forecast will need to be extended.

(c) *Forward planning*

Some contractors may wish to be advised of the weather prospects for several days ahead, especially where phased operations are involved. With this in mind, the 'Three days dry?' consultancy service has recently been made available to contractors.

Local environment

For a satisfactory forecast an adequate mental picture of the site and its surroundings is often necessary. In built-up areas, for example, increased surface roughness reduces the wind flow and the 'heat island' can affect temperatures. As a new structure rises above the surrounding buildings the effects of wind are felt increasingly so it is essential for the forecaster to know the height above the ground at which work is being performed. The gust is the important wind speed and at a height h the gust speed G_h is approximately given by the power law $G_h/G_{10} = (h/10)^{0 \cdot 085}$, where G_{10} is the gust speed at 10 m above ground level (a.g.l.). Thus at 50 m a.g.l. a 40 knot gust may, on average, be expected when a gust of only 35 knots is forecast at 10 m a.g.l. Table II shows this variation for other heights and gust speeds. In urban areas the effective 10 m height can be taken as 10 m above the general roof level.

Table II. *Variation of gust speed with height above ground*

Height above ground level *metres*					
10	20	30	40	50	60
Gust speed *knots*					
15	16	16	17	17	17
20	21	22	23	23	23
25	27	27	28	29	29
30	32	33	34	34	35
35	37	38	39	40	41
40	42	44	45	46	47

Topographical effects will often be present in some degree on construction sites and may be difficult to quantify. Over exposed hill tops, for example, gusts may be from 10% to 50% greater than gust speeds over level country—perhaps 50% greater for exceptionally prominent hills and for coastal cliff tops.

While much construction work takes place in urban areas, the civil engineering sector of the industry is frequently concerned with building roads, bridges and television masts in upland regions and these structures present some difficult problems in forecasting. For example, a site may be clear of fog all day owing to a local lifting of the cloud base in the lee of a high ridge. In the winter half-year a sharp contrast may exist between snow on the hill and rain in the valley. In moist warm sectors giving only occasional drizzle over low ground upland areas can sometimes have continuous moderate rain. In situations such as these the lack of representative observations makes forecasting more than usually difficult and the meteorologist should ensure that the uncertainties are appreciated by the contractor. Close liaison with the customer can soon lead to the forecaster learning the local peculiarities—even at a distance—and the standard of meteorological advice will improve.

Conclusion

There are few 'stop work' weather criteria which will always govern a particular outdoor activity on construction sites. Nevertheless, some understanding of the weather parameters that could halt or hinder operations can help the forecaster to concentrate his attention appropriately. Thus, with a little effort on the part of the meteorologist, a forecast can be given substantial relevance to construction work and so have a direct beneficial influence on the conduct of operations, thereby making a positive contribution to the whole project. A check-list of what the forecaster may need to find out is given in Table III.

Table III. *Check-list for forecasters*

(a) *Obtain information on:*
(1) exact location, altitude and extent of site, topographical details if possible,
(2) duration and character of project; materials, equipment and operations involved; dates between which particular operations are expected to take place,
(3) height of work above ground at various stages of the project,
(4) hours of work and whether 5, 6 or 7 day working weeks are planned, and
(5) method of transmission to be used for the forecast; address, telephone and telex numbers.

(b) *Agree with the customer:*
(1) threshold values for interference with work,
(2) threshold values for possible damage to newly completed work,
(3) optimum time(s) of day for the issue of forecasts,
(4) whether meteorological measurements will be made by the customer and whether these could usefully be communicated to the forecaster, and
(5) units in which wind speeds should be given.

Acknowledgement

The authors are grateful to Mr E. J. Keeble of the Building Research Station, Garston, for his valuable assistance in preparing Table I and its associated text.

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Notes and news

Retirement of Mr R. J. Ogden

Mr R. J. Ogden, B.Sc., Assistant Director (Public Services) retired from the Meteorological Office on 28 July 1981 after a career of 42 years.

Dick Ogden was educated at Whitgift School, Croydon, where he specialized in Mathematics and Physics and represented the school with distinction at Rugby Football. He joined the Office in September 1939 as an Assistant III experiencing through the war years the quick succession of postings through various Royal Air Force stations that was the lot of most of his colleagues at the time. Early in 1943 he was promoted to Assistant II and soon after was mobilized into the Royal Air Force, Meteorological Branch, serving as a dependent forecaster in the United Kingdom and south-east Asia until January 1946 when he was promoted to Flight Lieutenant, RAFVR, and qualified for duties as an independent forecaster. In the post-war reconstruction he was assimilated as an Assistant Experimental Officer and, while on posting as instructor at the Meteorological Office Training School, then in Alexandra House, Kingsway, he was able to resume his studies part-time, obtaining London University external degrees in Mathematics and Physics that enabled him to enter with success the Civil Service Competition for the grade of Scientific Officer.

In 1950, with a posting to London (Heathrow) Airport there began a particular association with civil aviation work that lasted until his retirement. He was promoted as an aviation forecaster to Senior Scientific Officer in 1953 and his growing interest and expertise in the international aspects of the work led to his selection as a member of United Kingdom delegations to meetings of the International Civil Aviation Organization and the WMO Commission for Aeronautical Meteorology where he quickly gained a reputation for the soundness of his arguments and judgements in technical matters. He was responsible for the United Kingdom contribution to the WMO Technical Note on high-level analysis and forecasting techniques. After a decade in this field Mr Ogden moved in 1960 to take up a post as a Senior Forecaster in the Central Forecasting Office, then at Dunstable, but soon transferred to the new Meteorological Office Headquarters at Bracknell. He was recognized as an outstanding senior forecaster, only that his characteristic thoroughness and attention to detail led sometimes to difficulty with tight schedules.

Following his early spell as a junior instructor at the Meteorological Office Training School, Dick Ogden continued to develop his talents as a lecturer both within the Office as a guest speaker on Senior Meteorologists' courses, for example, and extramurally to a wide variety of audiences, some with professional interests and some without. He was therefore well prepared for his next appointment in 1965 as head of the Training School, by then at Stanmore. Here he was involved in the early planning stages for the residential college at Shinfield Park that was to supersede the Training School, the general shape and scope of the new building and conversions owing much to his work at that time. Before he could see the project through to its conclusion, however, he was called in 1969 to take charge of the London Weather Centre which was then developing in its role as a key facility in the provision of services to national television and radio, the Press, the public and commerce and industry, especially the new offshore industry created by the discovery of the reserves of gas and oil in the North Sea. Before long he was a familiar figure in the corridors of Broadcasting House and the BBC Television Centre at White City and in the halls of British Gas, the Central Electricity Generating Board, British Rail, the departments and committees of the petroleum industry and the rest as he bent his energies to the reorganization of the Centre's work for them all. He revealed talents at this time as a radio and television broadcaster and, to the benefit of the Office, as a skilful interviewee. He continued to find time to give talks and lectures and was in demand as a member of selection boards of the Overseas Development Administration, the Crown Agents and the Civil Service Commission.

In 1975 Mr Ogden was rewarded with promotion to Senior Principal Scientific Officer and took up the post of Assistant Director in charge of Climatological Services, moving to become Assistant Director in charge of Public Services in 1978, thus returning towards the close of his career to the fields of public service and civil aviation in which he had already contributed so much. His final contribution to international civil aviation may turn out to be the most important since, in 1980, he took a leading role with other members of the ICAO Area Forecast Panel in laying the foundation for a new streamlined and more effective Area Forecast System. In public services he will want to be remembered for the efforts he has made to bring into being, after a gap of many years, two new Weather Centres, one newly opened in Bristol and the second, due to open later this year, in Cardiff. Typically, in his final year, he undertook a complete revision of the *Public Services Handbook*, enshrining in it much of the background and experience that he had gathered during the past ten years.

Dick brought to his career the personal qualities for which he was noted even as a young man: energy, strength of character and seriousness of purpose. As an administrator he wrote at length and in fine detail. He was not easily diverted from a course once his mind was made up. What he didn't get through at the Office he took home, working sometimes late into the night. He was responsible for a number of useful investigations usually closely related to his work at the time and had articles published in *Weather*, the *Meteorological Magazine* and elsewhere. For a time in the 1950s he was a member of the Council of the Meteorological Office Branch of the Institution of Professional Civil Servants, as Overseas Secretary and as Vice-Chairman. Some of his extramural interests overlapped with those of his vocation. He helped the Boy Scout movement in the development of the Weatherman and Meteorologist Badges, writing booklets and organizing courses for them at Scout Headquarters.

In 1953 while at Heathrow Dick married another meteorologist, Sylvia Kirby. He has shared with her since an interest in the heritage of Britain both natural and cultural that has led to countless expeditions into the country and to life membership of the National Trust. In his retirement Dick proposes, after spending a year or so in his present home in Camberley, to move out into the countryside and to find time for some serious carpentry. Sylvia and Dick will never be at a loss for things to do and we hope that they will long enjoy good health and contentment in their retirement.

Reviews

Atmospheric planetary boundary layer physics, edited by A. Longhetto. 245 mm × 170 mm, pp. x + 424, *illus*. Elsevier Scientific Publishing Company, Amsterdam, 1980. US $70·75, Dfl 140·00.

If you live in an attractive part of the world where the sun shines, the sea is blue and remains of history abound, you are indeed fortunate. You are even more fortunate if you have ambitions to improve the know-how of your local scientific community. Hold a lecture course. Invite top-level scientists from colder wetter climes as speakers, choosing a time in winter when they've almost forgotten what the sun looks like! You cannot fail; lecturers and students alike will enjoy every minute of it. And why not? Why not indeed! So, well done Sicily and well done the International School of Atmospheric Physics. You held your fourth course at Erice on the western tip of that sun-blessed isle in February 1978. I only hope the sun did shine for you (unfortunately I wasn't there to tell). And if perchance it didn't, better luck next time—at least you had some good lectures to listen to.

The course was devoted to 'Atmospheric planetary boundary layer physics' and attracted first-rate lecturers from Europe, the USA and Australia. The intention was to examine the current state of the art: the fundamental physical and mathematical modelling of the boundary layer itself and of the dispersion and transport of airborne pollution.

Not a snack for the beginner it's true, but a hearty meal for experienced scientists who wanted to learn from the experts. Being too good to let it slip by without putting it down in print, Professor Longhetto has brought all the lectures together into this book as a lasting repository. The chapters vary considerably in length and, I suppose, in interest to any one reader. I most enjoyed Svante Bodin's Chapter 1 on 'Applied numerical modelling of the atmospheric boundary layer', Bob Lamb's Chapter 6 on 'Mathematical principles of turbulent diffusion modelling' and the interesting juxtaposition of two chapters on plume rise by David Moore and by Pietro Bacci and Arnaldo Longhetto. Other readers would no doubt find their own favourite parts.

Much as there is to be gained and enjoyed from reading the book, I cannot help being reminded of a row of young lettuces after an attack by hungry slugs—however succulent the remaining morsels may seem, the gaps seem all too many and obvious. For example, the chapters on plume rise are excellent but who cares about plume rise unless it tells us something about likely ground-level concentrations? Not I, for one. (All right, I do really but only for rather subtle reasons!) And yet not a word about such things here, which only emphasizes what is obvious: the subject is now a very big one and there is no way that a course like this could contain it all.

Other parts by now seem a little dated. For example, results from the Minnesota experiment which for the first time investigated the structure of the whole depth of the boundary layer over land in various stability conditions are not included and are sorely missed. Nevertheless, don't be put off by this. The book is worth reading if you are a boundary layer meteorologist or have an active interest in pollution. It is well produced and does have a lasting value.

F. B. Smith

Ocean wave climate, edited by M. D. Earle and A. Malahoff. 250 mm × 160 mm, pp. xi + 368, *illus.* Plenum Press, New York and London, 1979. US $36·00 (+20% outside USA).

This volume contains the proceedings of the Ocean Wave Climate Symposium held at Herndon, Virginia, in 1977. It is concerned with the present state of knowledge of wave climate and with requirements for improving that knowledge. It is mainly concerned with coastal waters of the United States although the techniques described have quite general applications. The book is split into three sections. The first deals with wave models and with applications of wave data, the second deals with wave measurements and the third consists of recommendations from the symposium working groups. The second section will be of limited interest to most meteorologists since it deals mainly with the technical aspects of wave measurement. It concentrates on remote measurement by radar and several different methods are described. The first section is of more direct interest. Chapter 1 describes the National Meteorological Center (NMC) and Fleet Numerical Weather Central methods for analysing and forecasting sea surface winds. Many of the comments made about the NMC models are applicable to those used in the United Kingdom. The remaining chapters describe wave simulation methods used in the United States, ranging from very crude systems to the most advanced ones available and very thoroughly covering the field. There are also chapters on methods of determining the influences of waves on ships.

B. Golding

Obituary

We regret to record the death on 1 April 1981 of Mr M. A. Walsh, Scientific Officer, who was on the staff at Glasgow Airport. Mr Walsh joined the Office in July 1946 at Aberdeen as a Meteorological Assistant, and was promoted to Senior Scientific Assistant in January 1969. Most of his career was spent at Renfrew and Glasgow Airport, but he served overseas for a couple of years at Sharjah. For a number of years he acted as local representative for the IPCS and also the Civil Service Benevolent Fund.

We regret to record the death on 6 May 1981 of Mr C. E. ('Jim') Collins, Higher Scientific Officer, who was on the staff of London (Gatwick) Airport. Mr Collins joined the Office as a Meteorological Assistant in March 1941 and served at a number of outstations in the United Kingdom with most of his time being spent at Mildenhall. He was promoted to Senior Scientific Assistant in April 1956 and to Experimental Officer in October 1961. From 1970 to 1974 he served at Wildenrath in Germany and on his return was, after a spell at Thorney Island, posted to Gatwick in 1976. Mr Collins was fluent in French, German and Italian, and could also speak some Russian. He was an amateur radio enthusiast.

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