WRS
BS

Met.O.915

METEOROLOGICAL OFFICE

the meteorological magazine

JANUARY 1978 No 1266 Vol 107
Her Majesty's Stationery Office

METEOROLOGICAL OFFICE Met.O.915

THE METEOROLOGICAL MAGAZINE

No. 1266, January, 1978, Vol. 107

551.578.42(411):551.578.46

VARIATION IN THE FREQUENCY OF SNOWFALL IN EAST-CENTRAL SCOTLAND, 1708–1975

By GORDON MANLEY

(Emeritus Professor and Research Associate, Department of Environmental Sciences, University of Lancaster)

SUMMARY

For east-central Scotland records can be assembled of the number of days with snow or sleet observed to have fallen since 1754, with a reasonable extension back to 1708, by using a wide variety of sources from coastal Aberdeenshire to Pennine Yorkshire. From 1876 some official stations become available. Perfection in recording snow or sleet is infrequently attained; eye observation may be maintained throughout the 24 hours but in general is not. Attention paid to brief passing showers or rainy sleet can be shown to vary even among records from climatological stations; comparison is complicated by altitude, aspect, and distance from the sea. Station records can be broadly classified under four headings, the highest being that of official observatories and major operational airfields. The ratio between these categories is discussed; although routine observations by non-meteorological personnel commonly give much lower totals they remain in general consistent and useful. For the numerous stations, largely amateur, kept before 1880 allowances can be made based on inspection and comparison of original records. Sources are listed with estimates of class; conversion factors are given; annual totals at several stations are shown for comparison, those before 1770 being less certain. References are given to numerous little-known or neglected Scottish sources, some recently found. Results are shown in relation to the 1941–75 average; since 1876 they range from 0·4 (1957, 1959) to 2·1 (1879). The 1780s stand out, the 1880s less so.

INTRODUCTORY

Eighty years have elapsed since Mossman (1896, 1897a) produced his compilation of the Edinburgh observations since 1731, on which many have relied when seeking an index of past vicissitudes representative of Scotland. His massive papers followed earlier assemblages by Forbes and Buchan. Much can now be added; more early sources have been found, and we know more about the problems of assembly. The purpose of this paper is to assemble, standardize and discuss the available material with regard to the number of days on which snow or sleet have been observed and recorded as falling. The fact that beside Edinburgh the annual average at Turnhouse Airfield since its record began in 1949 is 31 while that at the Royal Observatory on Blackford Hill is 20 attracts immediate attention; what are future compilers to do when they set out to investigate variability if they are confronted by such results from two adjacent institutions of scientific repute? It will be demonstrated that both records can be reconciled, have value, and can be used.

It is everywhere evident that under existing rules the results of eye observations of this element differ considerably, even at adjacent stations at which we have no meteorological reason to suppose that there should be any serious or systematic difference in the annual totals. This is understandable; at the climatological stations that provide the majority, observers differ in age, scientific proclivities, the amount of attention they can pay to events out-of-doors, the number of hours on duty and interest in what happens outside these hours. Quite often they reside at some distance; moreover they must be expected to pass upwards of a quarter of their time asleep. The resultant differences, for North Wales and adjacent counties were discussed by Ashmore (1952), who concluded that four or possibly five types of station could be recognized. The present author (Manley, 1958) considered the observations at the stations around London and the Home Counties and showed that Ashmore's categories could be applied very well in that region; moreover, adjustments for altitude could be devised with the aid of such records as those from Croydon, Biggin Hill and Little Rissington among the airfields, or Hampstead, Rothamsted and Whipsnade among the climatological stations.

In an earlier paper (Manley, 1940) based on observations from 1912 to 1938 over the British Isles, when there were few operational airfields, it was necessary to draw up the map of annual averages of 'days with snow' on the basis of 'good climatological standards'. These are still effective for most working purposes and can continue to provide, as at Blackford Hill, a useful picture of distribution and reasonable standards of comparison. But now that we have a widespread network of airfields at which professional observers keep, in general, a constant watch and for obvious reasons are alert to the first appearance of small amounts of sleet in cold rain, or those brief flights of snowflakes that so often drift down on the margin of an anticyclone, especially in eastern Britain, we can make comparisons and allowances for differing types of station in many districts, for example around Manchester. In particular, we can examine and compare the totals at numerous stations in eastern and central Scotland in considerable detail. We have upwards of 25 years from Leuchars and Turnhouse, with other airfields similarly exposed at no great distance, with a similar expectation of the incidence of those airstreams and synoptic situations likely to provide air cold enough for sleet, at least, to be observed down to sea level. Accordingly we can consider Acklington, Leeming, Dishforth and Dyce. Inland at a higher altitude Eskdalemuir Observatory, like Kew and Lerwick, can also be expected to provide 'first-class' observations. Prestwick and Abbotsinch demonstrate the result of being situated on the more sheltered western side of Scotland.

We can illustrate these trends by setting out for comparison the averages for 1961–75 at a selection of lowland stations (below 200 feet) around Edinburgh and across to the Tay, the number of days being rounded to whole numbers for convenience.

A. Turnhouse 34, Leuchars 34 (Acklington 36, Dishforth–Leeming 34 approx.)
B. Pitreavie 25, Montrose 27 (Tynemouth 30).
C. East Craigs 20, Haddington 21, Dundee 22, Perth est. 21, Carnoustie est. 20, Kirkcaldy 20.
D. Botanic Gardens 17, Dunbar 15, Arbroath 13, St Andrews est. 16.

Some comparable figures can be added here, taken from the old *Book of Normals* (1881–1915) for periods between 1876 and 1920.

Aberdeen (Obsy) 34.0, Dundee 25.1, Leith 17.2, Shields 22.6, Sunderland 27.9, also Glasgow (Obsy) 16.5. (Durham (Obsy) 1881–1920, 33.1, can be added from the MS. record.,

For 'Edinburgh' the 1881–1915 average is (approximately) 22, based on three stations in extension of Mossman's series. The low figures at Leith (a 'telegraphic' station) and Glasgow (Obsy) are noteworthy.

In broad terms we can recognize here a group (A) of active airfields; (B) a few exceptional climatological stations, such as are sometimes maintained under the auspices of universities or professional engineers, but which are not likely to be alert through the night, while (C) and (D) form the majority of the climatological stations. Some of the (C) stations, typified by the agricultural institutes with an obvious interest in weather, have resident staff who have reason to be observant, and may visit instruments twice daily, whereas (D) include many at which instruments are visited once daily, and while such stations can provide very consistent observations over long periods, these observations are likely to be made by staff who have other duties during the working day, and who subsequently depart to reside at some distance. It is clearly not possible to make a precise distinction between (B), (C) and (D); but if for any one station the annual totals are entered beside those of one or more adjacent stations the effect of a change in the observational routine can generally be seen at once. For example, compare for 1925–50 the following:

Leuchars 22.2, Perth 21.6, Dundee 17.9, Arbroath 16.1.

But for 1951–70 we have Leuchars 32.2, Perth 23.5, Dundee 23.7 and Arbroath 16.3. From 1955 onwards Leuchars agrees closely with Turnhouse. 'Amateur' stations are now very few; they may fall into any class, as was demonstrated by the older West Linton observations at the station established early in this century by the Revd J. Begg, a well-known member of the Scottish Meteorological Society before its amalgamation with the Royal Meteorological Society in 1921. Near London, the late E. L. Hawke likewise recorded nearly twice as many days with snow as did observers at some neighbouring stations.

In colloquial terms, we find the climatological stations which can be presumed to record 'conspicuous snow or sleet during the working day' (D); some would add to that 'noticeable snow' (C); some might be considered as 'careful observation throughout waking hours' (B), and at the active airfields 'meticulous observation throughout the 24 hours', or nearly so (A). In the minds of the non-meteorological public (D) may well be representative. Ashmore in his original paper provided a series of equations relating these categories; an 'A' station should be expected to give one-and-a-quarter times the average given by a 'C' station, plus five days. Scotland tends to have slightly more in the way of passing showers and it might be expected that the difference between 'A' and 'C' averages would be a little greater. I have accordingly taken out a number of comparisons among the available Scottish and northern English stations from which it seems reasonable to modify Ashmore's relationships as follows:

$$A = 1{\cdot}1\ B + 4 = 1{\cdot}3\ C + 6 = 1{\cdot}5\ D + 8.$$

This means that in the north an operational airfield will commonly average about twice the total given by routine climatological stations at the same level.

The rate of increase with altitude, about 1·5 days/100 feet for 'A' stations in southern England and 1.0 for the climatological stations, increases through northern England and southern Scotland to the central Highlands; in southern Scotland it appears to average fully twice that applicable in the south. For example over the period 1961–75, averages close to 20 prevail on the low-lying land round Edinburgh, 35 to 45 at 700–800 feet (Blyth Bridge, Carnwath, Stanhope Farm) and 50 at Leadhills (1270 feet) among the climatological stations, which works out at between 2 and 3 days for each hundred feet, but it is a little difficult to discount the possible consequences of conditional instability in the region of the Lammermuirs and Pentlands. To quote some of the averages for 1961–75 we have, from this area:

Blyth Bridge (830 ft) 44, Carnwath (706 ft) 42, Stanhope Farm (741 ft) 34, West Linton (800 ft) 28, Penicuik (620 ft) 33, Bush House (605 ft) 24, Blackford Hill (441 ft) approx. 21, but including 5 estimated years. The older stations on the upland outskirts of Edinburgh (Bangour, Boghall, Balerno) show similar differences.

THE EARLIER OBSERVATIONS

Decision with regard to the several categories of observation and entry of snow days must largely be a matter of judgement based on careful review of the appearance of the original entries and comparisons of the available totals. This applies to all the earlier observations, whose provenance will now be discussed.

Daily observations at stations under the control of the Scottish Meteorological Society, e.g. Braemar, were first organized in 1856, but 'days with snow' were not separately totalled until 1903. For a few 'telegraphic' stations (e.g. Aberdeen, Shields) and some second-order (e.g. Dundee) stations under the Meteorological Office, totals of days with snow are available from 1876 or soon afterwards, and in northern England the Royal Meteorological Society's second-order stations provide totals from 1874 onwards. Before this time it is necessary to search the MSS. or contemporary printed sources, and in many cases to count up the entries for each month; sometimes this gives an opportunity to estimate the observer's characteristics. For example the MS. (1771–81) of George Watson of Fiddes, a farmer close to the shore at Foveran, a few miles north of Aberdeen, soon gives the impression that he did not record snow on many of those days, so common along that coast, with passing showers of sleety rain on a raw easterly wind which but a short distance inland would fall as wet snow and might even provide a cover. Even today the differences between Mannofield, Craibstone and Dyce are very evident, more than is readily attributed to difference of level.

Mossman's massive assemblage for Edinburgh, already referred to, provides an overall average of 21 days with snow from 1771 to 1895; this happens to be remarkably similar to that of the climatological record maintained at the Royal Observatory on Blackford Hill (1903–67, 21 days). But Mossman does not appear to have been particularly critical of the snow observations, as may be judged from the comments on his paper on the London snow observations from 1713 onwards (Mossman, 1897b). Those which he assembled from a varied succession of Edinburgh observers clearly differed considerably in 'character of observations'. In the tabulation below we note some very low annual totals during the 1850s, a period when the Edinburgh observations depended on brief newspaper reports published from Adie's shop in Princes Street and, later on, on the observations made by a detachment of Royal Engineers engaged on the Ordnance Survey.

In order to overcome these difficulties I have collected and tabulated other series of annual totals, several from manuscript sources hitherto unused. Moreover, Scotland is rather short of snowfall observations between 1845 and 1875, unless we go as far north as Culloden (Arthur Forbes series, 1841–80); hence I have made use of records from the adjacent north of England (Newcastle upon Tyne 1802–33, Durham University Observatory 1848–1950, Sunderland 1857–1913 and Kendal 1830–70, together with a very good daily record from the flanks of the Pennines at Braithwaite above Keighley 1807–57). These assist the linkage of the earlier nineteenth-century Scottish records, e.g. Aberdeen 1799–1810, 1829–41; Perthshire 1804–32, 1865–74. In the *Journal of the Scottish Meteorological Society* for 1878 there is a summary of a Cruickshank record at Aberdeen, 1857–77, hard to interpret as he counts 'snow' and 'sleet' totals separately and they overlap; I have not yet found his original MS. For the later 18th century we have a recently discovered MS. meteorological journal, of very good quality, from Belmont Castle near Meigle in east Perthshire (1771–99) as well as the above-mentioned Foveran journal and that kept at Mause, north of Blairgowrie, 1754–74. I have also included totals (1785–1809) from the excellent record kept further west at Cambuslang near Glasgow. These are all in addition to the well-known Gordon Castle record (1781–1827) discussed by Buchan (1880) from further north in Moray, and they lie nearer to the Forth–Tay region in which we are primarily interested. Too much weight should not be given to observations from north of Aberdeen and the main Grampian watershed, and some brief earlier records at Aberdeen (1767–70), Selkirk (1768–70) and Kirkcaldy (1775–78) have for various reasons been omitted, while Rothesay (1818–30) lies too far west, and Carbeth Guthrie (1817–59) does not include snow.

Before 1754 daily observations are scarcely to be found in Scotland, despite considerable search. From the brief Edinburgh series used by Mossman (1731–36) it looks as if the daily entries merely refer to the weather at the time of observation. A little use can be made of Daniel Hasting's interrupted MS. record at Alnwick in Northumberland (1739–46). There are also the MS. weekly reports (1749–60) sent by the Earl of Bute's head gardener, Alexander McGrigor, from Mountstuart near Rothesay, but these are not sufficiently detailed to provide a good count of 'snow-days'. Hence one must again make use of Yorkshire journals from the flanks of the Pennines; notably, a recently discovered MS. for the neighbourhood of Dewsbury (William Elmsall, 1708–40) and Dr Thomas Short's MS. for Sheffield, 1734–55, together with Dr Nettleton's short series at Halifax, 1724–27.

That there is broad agreement between the fluctuations in Pennine Yorkshire and east–central Scotland, given the provenance of most of our snow on winds with an easterly component, can readily be demonstrated. In a simple form it appears in the diagram showing, in regard to frequency of snow, the general correspondence between the decadal running means from London through the Midlands and Edinburgh to Gordon Castle (Manley, 1969). For the London area, the observations can be standardized from 1668 onwards. To do the like for eastern Scotland set a much greater problem; stations are further apart, relief and consequent orographic effects are much greater and more varied. One cannot for example link the old Aberdeen Observatory record with Dyce, Craibstone or Mannofield.

From the experience gained when Miss Shaw and I set out to assemble data from journals kept in the London area it became evident that, in regard to snow, the majority of the 'amateurs' before the days of officially organized observations produced results comparable with the 'C' and 'D' climatological stations today. To quote: George Smith, who had retired from his post as Queen Anne's Proctor, kept his journal at Richmond from 1713 to 1745. Over the years 1729–45 he produced an annual average of 8·7 days with sleet or snow; this is about the same as the Wisley average today. For the same period Dr James Jurin, who was not only an active physician but also Secretary of the Royal Society, produced an average of 12·5; it seems reasonable to treat these as 'D' and 'C' respectively. Jurin's average is further supported by Hooker in north Kent and at Tonbridge. Later, between 1786 and 1807, Hoy at Sion House averaged 13·8, Bent at Paternoster Row 18·4. Howard's average beginning in 1797 was about the same as Hoy's during the period of overlap, and distinctly below that of Belville at Greenwich, who began in 1811. Hence for purposes of reduction to a common standard it is reasonable to regard Bent and Belville as 'B', and Hoy, Jurin and Howard as 'C', while Smith, as 'D', produces results comparable with those of the Royal Horticultural Society's later Chiswick record, also 'D', which began in 1826 (regard being paid to the effects of intermittent severe seasons). Between London and Yorkshire, 18th-century averages can also be compared with the results from the long and apparently very consistent daily observations (1748–63, 1777–89) kept by Thomas Barker at Lyndon in Rutland, which are to be reasonably regarded as 'C'.

The interesting point is that few of these early journals give, for snow-days, averages so low as to lead one to rank them much below 'D', just as they are rare today. Cary's record kept in the Strand (1786 onwards) gives such low figures as to lead to the suspicion that his observers merely noted the weather at the time when they read the instruments; the like applies to Cowe's journal (1797–1838) at Sunbury-on-Thames; in Scotland, the early Edinburgh journal (1731–36) has already been mentioned.

Among the Scottish stations the early record from the farm of Mains of Mause, at about 600 feet 4 miles north of Blairgowrie, is also regarded as a definitely low 'D'. There is only a very brief overlap with either Belmont Castle (on inspection, probably 'C', and generally comparable with the near-by Kettins agricultural station in this century), or with the much more distant Sheffield, which again, when compared with Barker's Lyndon averages, must be ranked as 'D'. Within a few miles there is also the daily MS. record of weather (non-instrumental) entered by James, Duke of Atholl from November 1755 to December 1763. This I have very recently inspected among the Atholl MSS. through the courtesy of the Aberdeen University Library and the Atholl Estates Office. Most of it refers to Dunkeld House, only 10 miles distant, and the Duke's frequency of days with sleet or snow is consistently about 1·5 times that at Mause. Detailed comparison of daily entries confirms that the observer at the farm paid little attention to events in the night, or to the slight passing showers characteristic of eastern Scotland, or to days when rain probably predominated over sleet. A single year's observations (1762) by Skene at Aberdeen this judgement of the Mause journal as far as snow is concerned. The overall support average of 22 days in a period not characterized by a predominance of mild winters certainly looks low (Crieff, at 478 feet, averaged 27, Kettins and Perth 21, between 1914 and 1938; incidentally, over the period 1922–38 Leuchars also averaged 22).

This is not to say that past averages, especially in the late 18th century, should be the equal, or nearly so, of today's; the evidence does suggest that decadal averages are likely to range between about 0·8 and 1·4 times those of our present experience, i.e. the last 30–40 years.

Much of Mossman's long Edinburgh series likewise depends on 'climatological observations' lying from 'D' to 'C', if not indeed even lower for occasional periods, as we have seen. In order to continue his series after 1896 we can use the climatological record kept at the Blackford Hill Observatory, whose purpose is primarily astronomical. Like the older Glasgow University Observatory, Blackford Hill, as we have seen, gives comparatively low figures (average 21) but they are to all appearance very consistent and the product of a well-established daily routine until 1967, after which there are some gaps. It can also be noted that from 1887 onwards to 1896 Mossman's figures were those of his own station and that they too were lower than the annual totals for 'Edinburgh' as reported in '*Observations at stations of the Second Order*'. There is also an overlap with the old Leith observations (1876–1920) for which the *Book of Normals* quoted an average of 17, much below those then given for Aberdeen (34), Dundee (25), or Shields (23); it would therefore be reasonable to treat Leith as 'D', despite the fact that, with Aberdeen and Shields, it was a telegraphic station adjacent to the North Sea.

The list of older records and their classification for purposes of standardization is given below. In several instances it is also necessary to consider what adjustment should be made for altitude. This is not always easy in eastern Scotland as one must try to distinguish the effects of sharply rising coasts in Aberdeenshire, or hills such as the Lammermuirs and the Pentlands, in triggering off the instability showers so characteristic of winter and spring, from the effect of altitude alone. High totals since 1960 at Dyce (242 ft) are noteworthy.

Good climatological stations close to the east coast give averages between 20 and 30 south of Aberdeen and north of the Tees. Inland at 280–360 m (900–1200 ft) where we have Balmoral, Braemar, Dalwhinnie, Glenmore Lodge, Achnagoichan, Braes of Glenlivet, Tillypronie, and Kindrogan for example, averages around 60 are more general and this would suggest a rate of increase of between 3 and 4 days/100 ft in the eastern Highlands; the lack of first-class airfields at higher altitudes, however, makes it difficult to say how much larger the rate of increase would become for 'A' stations.

What is clear is that the rate of increase of the annual average frequency of 'snow-days' with altitude is considerably more rapid in Scotland than in south-east England; this of course might fairly be expected having regard to the greater frequency of small amounts of precipitation in the form of light passing showers accompanying the prevailingly greater lapse rate in the lower layers of the atmosphere. In broad terms the rate of increase for the North Pennines–Borders is about twice that in southern England (cf. Bellingham, Leadhills) and approaches three times as great in the Highlands. Lamb's two-way relationship between occurrence of snow and the thickness pattern (Lamb, 1953) can also be recalled, together with the northward decline in the average height of the freezing level (Murray, 1950).

It is noteworthy that in the central Highlands the numbers of days with snow by 'C' or 'good climatological observation' becomes about equal to the number of days with snow-cover at around 300–360 m (1000–1200 ft). But at still higher altitudes persistence of snow-cover is largely a function of the departure of temperature below the average together with frequency of snowfall. With the aid of the observations of the Snow Survey and other upland records it has been demonstrated how much more rapid is the increase with altitude in persistence of snow-cover on the mountains of northern Scotland, compared with the south (Manley, WMO Norwich Meeting, 1975).

Representative yearly totals since 1708 are given in the columnar diagram (Figure 1) as ratios, to single decimals, of the average for 1941–75, regarded as unity. This average had been calculated from the annual totals at 10–12 stations between Dishforth in North Yorkshire and Craibstone, centred on the Forth–Tay region; apart from the airfields, stations have been chosen with to all appearance consistent records whose category can be fairly judged and allowed for; effort has also been made to allow for altitude. The annual totals at a number of the most useful stations are tabulated, from which it will be evident that even today there must frequently be an element of judgement in the weighting of the figures. This applies increasingly with regard to all the observations before about 1900. Before 1771 we are largely dependent on distant stations and on single series with little corroboration. These early years should therefore be treated with additional caution until, perhaps, more observations come to light.

This paper would become too long if an attempt were made to standardize the figures for the individual months. It might perhaps be done roughly by noting for each month the percentage of each year's total of 'snow-days'. Those who wish to pursue the events of individual seasons should go to the original sources, taking account of the quality of the observations, the prevailing winds and the departure of the temperature above or below normal. Persistence of cold unsettled weather in spring (March–May) is likely to be the main factor leading to prolongation of the mountain snow-cover, even into July at the highest levels; for example, in 1885 on Ben Nevis. To discuss extremes of occurrence should likewise be the subject of a separate paper; at the lowland stations, occasional mention of snow in late September or early June suggests that for eastern Scotland these are limits of long standing. The report of snow lying down to 1700 ft, with sleet at 800 ft on Speyside as early as 10 September in 1976 has not often been surpassed. There remains much room for discussion of the probable amplitude of fluctuations in western Scotland, especially towards the sea. Unfortunately there is a lack of continuity and of adequate observational material; practically all stations are coastal. Even in the Glasgow area the very evident difference, taking account of temperature, between the standards of observation maintained at the old Glasgow University Observatory (1868–1921) as reported in Becker's *Geophysical Memoirs* of 1925, and those of later stations such as Paisley, Springburn Park and Renfrew–Abbotsinch make for difficulties in assessment, although these again can be reasonably resolved on the assumption that the older climatological station falls into the 'D' group in regard to snow. In Ayrshire, over 30 years, Prestwick averages 23 and Auchincruive 16; this shows the characteristic difference between an active airfield ('A') and a near-by active agricultural research station with evident interest in weather (very good 'C' or low 'B').

While there are those who may question the utility of assemblage of such data, dependent as it must be on the exercise of judgement with regard to the manner

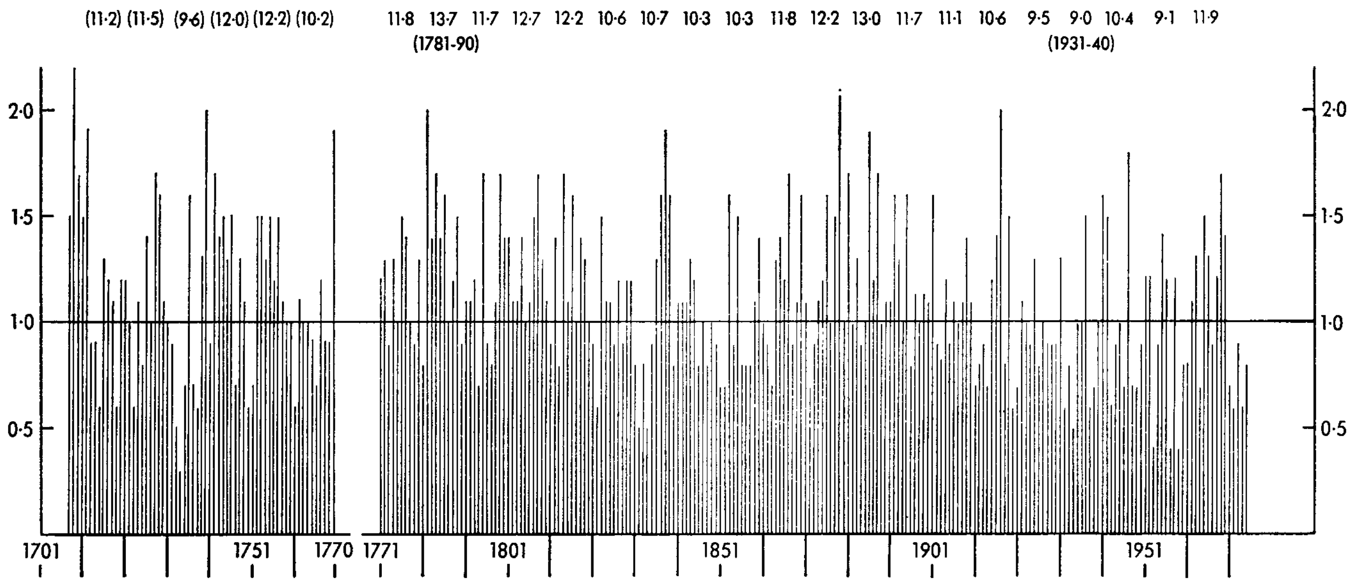

FIGURE 1—ANNUAL FREQUENCY OF SNOW-DAYS IN EAST-CENTRAL SCOTLAND, 1708–1975

Totals are shown for each decade; values before 1771 are less reliable than subsequent ones; 1·0 = average for 1941–75.

in which eye observations have been kept, the opportunities, and the criteria in vogue among earlier observers, this paper will serve to extend, reinforce and improve on Mossman's much-used Edinburgh compilation. It may also serve to draw attention to the immense mass of older meteorological journals and material awaiting critical examination by those interested in climatic fluctuation in these latitudes. Fluctuations in the frequency of snow when averaged over decades are closely associated with fluctuations in the temperature of the winter months (November to April) and can be used to assist in the reduction of earlier temperature records, whose dependence on imperfect instruments, exposures and techniques leads one to seek such other means of corroboration as may be found. Scotsmen eager to investigate the meteorological conditions prevailing on particular days since the earlier 18th century may also find the list of sources convenient.

I have to express my thanks to the Shell Organization for a personal research grant in aid of work on past records; to the Marquess of Bute for the privilege of examining manuscripts in his private library, and the help of his archivist Miss Armet, to the Librarians in charge of manuscripts in the National Library of Scotland, and quite recently, to the Atholl Estates Office; to the university libraries at Aberdeen, Glasgow, St Andrews and Durham; to the City Library at Sheffield, also to those of Perth, Inverness and Keighley; to the Meteorological Office Edinburgh with its collection of older Scottish journals; to the Scottish National Record Office, and to the County Record Office at Kendal. Lastly, it remains a pleasure to acknowledge much help from Miss Elizabeth Shaw in earlier work on Scottish snow.

I am indebted to the officers of the Royal Society, the Bodleian Library, and the British Museum for the opportunity to consult MSS.

REFERENCES

ASHMORE, S. E. 1952 Records of snowfall in Britain. *Q J R Met Soc*, **78**, pp. 629–632.

BUCHAN, A. 1880 The meteorology of Gordon Castle, Banffshire, 57° 38′ N. LAT., 3° 4′ W. LONG., from July 1781 to November 1827, from observations made by James Hoy, F.L.S. *J Scot Met Soc*, **5**, pp. 59–83.

LAMB, H. H. 1955 Two-way relationship between the snow or ice limit and the 1,000-500 mb thicknesses in the overlying atmosphere. *Q J R Met Soc*, **81**, pp. 172–189.

MANLEY, G. 1940 Snowfall in the British Isles. *Met Mag*, **75**, pp. 41–48.

1958 On the frequency of snowfall in metropolitan England. *Q J R Met Soc*, **84**, pp. 70–72.

1969 Snowfall in Britain over the last 300 years. *Weather*, **24**, pp. 428–437.

MOSSMAN, R. C. 1896 The meteorology of Edinburgh, Part I. *Trans R Soc Edin*, **38**, pp. 681–756.

1897a The meteorology of Edinburgh, Part II. *Trans R Soc Edin*, **39**, pp. 63–207.

1897b The non-instrumental meteorology of London, 1713–1896. *Q J R Met Soc*, **23**, pp. 287–298.

MURRAY, R. 1950 Freezing level over the British Isles. *Weather*, **5**, pp. 284–287.

TABLE I—NUMBER OF DAYS WITH SNOW AT SELECTED STATIONS IN EAST–CENTRAL SCOTLAND AND NORTHERN ENGLAND

	ENGLAND, NE					SCOTLAND					ENGLAND	
		Halifax			Yorks	Perthshire		Edin	Fov	Moray	Lanark	
	Dews	Sheffield	Alnwick	Year	Sheff	Mause	Meigle	(Moss)	Aber	G.C.	Cambg	Kendal
				1751	10							
				1752	23							
				1753	23							
				1754	25	23						
				1755	32	22+						
				1756		21						
				1757		27						
1708	22			1758		20						
1709	33			1759		13						
1710	26			1760		16						
1711	22			1761		10						
1712	29			1762		21						
1713	13			1763		18						
1714	13			1764		18						
1715	9			1765		17						
1716	20			1766		12						
1717	18			1767		22						
1718	16			1768		17						
1719	10			1769		16						
1720	18			1770		35						
1721	22			1771		23	(24)	20	29			
1722	15			1772		40	(25)	34	27			
1723	9			1773		21	(11)	14	19			
1724	17	16		1774		29	(22)	24	28			
1725	12	12		1775			(21)	16	12			
1726	22	19		1776			(35)	26	24			
1727	15	15		1777			(29)	27	30			
1728	25			1778			(27)	10	19			
1729	24			1779			(17)	16	14			
1730	17			1780			(32)	28	17			
1731	15			1781			(11)	12	13			
1732	14			1782			48	47		58		
1733	8			1783			28	32		48		
1734	5	3		1784			52	(26)		47		
1735	11	13		1785			30	26		57	29	
1736	24	19		1786			36	32		52	24	
1737	10	17		1787			25	13		18	11	
1738	9	12		1788			34	17		32	19	
1739	20	20		1789			37	21		52	35	
1740	30	28		1790			22	13		16	13	
1741		11	21	1791			28	10		26	26	
1742		26	—	1792			30	17		42	17	
1743		19	35	1793			37	13		45	21	
1744		23	26	1794			13	10		18	12	6
1745		20	27	1795			47	35		39	25	19
1746		24	30	1796			25	8		31	10	10
1747		11		1797			22	9		34	8	8
1748		20		1798			34	13		40	17	9
1749		16		1799			(45)	33	34	43	29	21
1750		9		1800				28	25	32	14	13

TABLE I—*continued*

	SCOTLAND						ENGLAND, N		
	Edin	Aber (Town)	Perths	Kincd (Johns)	G.C. Cull	Cambg Duns	Newc Durh	Braith	Kendal
1801	35	39+			44	24			15
1802	24	27			67	21	17		16+
1803	24	25			40	26	26		11
1804	33	33	(30)	(34)	56	19	27		16
1805	14	31	25	32	38	14	22		10
1806	22	23	(27)	25	44	24	18		13
1807	29	44	(30)	42	48	27	30	59	30
1808	33	41+	(45)	53	67	30	35	61	24
1809	30	39	33	37	61	(27)	26	40	12
1810	20	41	26	25	52		18	31	
1811	20		18	24	34		16	30	
1812	32		33	35	34		30	50	
1813	15		(15)	18	29		20	26	
1814	45		38	35	43		46	53	
1815	26		22	23	34		24	35	
1816	40		46	40	63		24	53	
1817	26		25	21	48		13	31	
1818	35		34	15	49		30	46	
1819	37		27	30	22		16	41	
1820	22		14	23	47		20	40	
1821	18		17	(20)	33		7	22	
1822	13		(13)		29		12	18	
1823	33		36		36		29	53	
1824	23		(18)		35		18	38	
1825	24		(15)		39		18	34	
1826	19		13		37		18	26	
1827	21		24		47		35	46	
1828	20		15				22	31	
1829	21	(30)	19				35	50	
1830	26	23	23				35	43	32
1831	18	18	13				16	29	16
1832	7	5	(8)				8	14	9
1833	16	16					(17)	35	11
1834	8	5						12	1
1835	10	18						35	21
1836	21	23						52	35
1837	42	31						50	34
1838	46	52						56	30
1839	30	35						51	40
1840	15	17						32	15
1841	22	18			36			35	25
1842	25	26			19			37	22
1843	19	46			44			43	18+
1844	28	37			50			41	29
1845	16	27			45			37	29
1846	11	29			46	14		14	12
1847	7				44	30		31	19
1848	7				27	(25)	21	33	17
1849	17				29	(27)	21	38	23
1850	12				38	(20)	16	23	(20)

	SCOTLAND									ENGLAND, N		
	Edin	Edin (B.H. etc)	Aber (Obsy)	Moray (Cull)	Crieff Braem	Dundee	Duns March	Shields	Sund	Durh	Braith	Kendal
1851	4			16			22			18	19	(10)
1852	6			31			15			13	15	(10)
1853	23			53			43			38+	48	42
1854	13			46			21			(18)	21	17
1855	33			58			44			(40)	49	42
1856	3			39			29			15	18	14
1857	11			29			24		(20)	16	(18+)	21
1858	14			36					15+	15		17
1859	17			58					24	18		18
1860	23			53					48	30		44
1861	18			33					23	19		24
1862	16			29					24	12		14
1863	8			26					15	(15)		12
1864	21			34					33	(34)		18+
1865	21			45	40				42	(23)		28
1866	9			46	(35)				31	(20)		25
1867	31			54	29				46	(40)		37
1868	11			35	32				21	15		23
1869	15			40	26				35	21		22+
1870	32			40	37				43	38		(35)
1871	17			32	35				26	26		
1872	11			26	31				16	16		
1873	12			23	(32)			(17)	26	19		
1874	21			41	30			(22)	28	(21)		
1875	20			23				(30)	35	23		
1876	36		32	47				31+	43	44		
1877	13		32	53				24	20	28		
1878	19		42	38				45	37	31		
1879	31		58	33				62	59	55		
1880	12		39	23	38			24	18	24		
1881	25		(59)		42	38		(45)	42	(41)		
1882	14		(33)		50	26		(25)	15	(21)		
1883	27		(48)		50	33		(30)	26	(28)		
1884	13		(25)		39	31		8	17	(20)		
1885	14		30		58	23		15	23	(20)		
1886	37		60		52	55	65	33	49	64		
1887	19		38		45	25	37	28	32	54		
1888	25		50		42	44	59	38	49	64		
1889	13		37		45	19	29	21	28	37		
1890	18	26	26		27	19	25	16	29	31		
1891	17	20	31		32	25	33	23	29	35		
1892	33	36	52		48	32	30	38	52	60		
1893	17	26	38		44	30	32	26	26+	39		
1894	15	20	29		48	26	31	17	20	28		
1895	30	36	64		62	34	25	35	42	53		
1896	10	11	26		34	25	12	14	13	22		
1897		20	41		44	23	22	26	27	41		
1898		18	37		45	15	17	24	24	27		
1899		18	35		51	25	29	24	25	35		
1900		(25)	26		48	25	28	27	24	38		

TABLE I—*continued*

	SCOTLAND								ENGLAND, NE			
	Edin (B.H.)	Aber (Obsy)	Braem	Balm	Dundee	Perth	Leuch	March	Shields Tynem	Sund Ackl	Durh	Eskd
1901	(26)	54	36		33			40	38	42	41	
1902	(17)	33	38		19			19	13	17	25	
1903	11	23	43		9	(15)		(21)	21	26	28	
1904	29	22	43		32	22		36	22	26	31	
1905	13	23	33	30	20	(14)		27	15	21	30	
1906	19	44		55	28	11		25	32	34	40	
1907	22	32		43	21	13		27	21	20	24	
1908	19	33		46	21	(21)		35	17	25	29	
1909	29	46		42	22	22		37	34	36	39	
1910	25	30		40	13	19		28	20	22	34	32
1911	14	19		30	9	6		22	9	14	18	40
1912	20	30	36	39	10	9		18	18	17	17	42
1913	24	19	49	39	17	23		21	16	(17)	23	35
1914	24	15	57	26	4	10		12	3		14	26
1915	28	38	77	46	12	23		27	12		35	49
1916	34	38	57	59	33	27		39	12		36	55
1917	46	68	67	94	36	41		39	31		54	75
1918	18	27	33	50	14	13		20	11		16	41
1919	44	48	79	94	29	27		28	19		(36)	92
1920	9	20	36	35	14	8		8	7		14	17
1921	14	26	40	34	16	15		14	6		9	32
1922	23	49	59	53	(15)	19	31	30	24		29	48
1923	18	42	51	37	10	21	18	23	19		22	46
1924	11	34	32	36	13	17	24	23	21		16	32
1925	23	45	51	48	20	31	31	32	28		25	54
1926	10	29	50	25	10	24	17	14	17		25	39
1927	15	40	35	27	14	37	23	21	22		20	47
1928	15	39	47	39	9	24	21	22	18		17	45
1929	9	42	41	28	10	26	22	19	23		21	46
1930	11	37	41	33	14	21	18	22	18		24	76
1931	21	48	50	34	32	25	34	23	29		24	73
1932	6	30	33	29	11	8	21	10	11		17	57
1933	17	29	27	26	11	8	18	18	21		21	43
1934	12	20	28	29	9	11	10	10	8		10	44
1935	24	32	50	41	20	22	13	17	23		20	53
1936	20	34	45	46	12	22	17	29	18		17	52
1937	36	57	49	54	26	26	36	30	34		37	71
1938	15	20	23	23	16	15	12	11	12		12	40
1939	12	23	38	25	14	13	13	16	12		15	39
1940	18	39	43	29	24	18	25	19	27		22	43
1941	35	50	69	54	35	34	41	33	33		29	57
1942	32	53	56	31	33	32	32	21	27		(43)	54
1943	10	24	45	16	9	13	10	11	11		13	31
1944	20	42	66	33	20	20	20	12	14		17	55
1945	20	37	38	20	28	18	20	21	20	21	21	42
1946	16	30	47	17	16	11	14	11	12	13	13	40
1947	38	59	73	37	33	39	48	(17)	37	54	44	70
1948	13		40	28	14	27	17	(16)	8	13	8	41
1949	13	15*	51	29	14	17	23		10	14	12	43
1950	17	26*	56	—	11	24	22		19	26	26	43

*Turnhouse

	SCOTLAND									ENGLAND, NE			SCOTLAND	
	Edin B.H.	Edin Turnh	Edin E.Craig	Aber Manno	Braem Balm	Dundee	Perth	Leuch	March	Tynem	Ackl	Durham (Hough-all)	Eskd	Dyce
1951	26	38		32	88	25	26	30		23	32	37	73	
1952	24	34		24	65	23	23	33		30	47	40	56	
1953	9	11		(15)	36	10	11	10		14	14	13	23	
1954	20	22		24	56	23	22	28		22	26	20	44	
1955	40	39		(50)	76	39	28	46		35	46	37	58	
1956	24	35		40	67	24	25	36		29	44	36	51	
1957	9	20		13	37	6	9	8		10	8	10	32	
1958	23	39		41		33	22	39		34	37	34	49	
1959	6	13		19		14	9	10	10	12	10	10	27	
1960	10	23	16	26		19	14	23	22	20	26	23	34	
1961	16	25	19	31	36	20	20	23	21	28	27	18	42	45
1962	21	32	31	36	61	26	20	29	36	33	39	30	69	55
1963	31	43	29	(37)	52	29	23	40	42	46	48	33	58	57
1964	12	26	13	18	41	10	13	21	13	18	27	12	50	22
1965	28	46	27	(46)	86	40	27	46	43	45	52	27	71	75
1966	21	44	23	40	66	28	32	44	32	31	48	18	88	64
1967	16	31	13	(25)	55	18	12	28	21	22	33	20	64	57
1968	—	44	27	26	53	25	23	45	36	43	47	23	69	66
1969	—	57	29	44	75	35	35	56	43	57	61	36	81	69
1970	(21)	48	26	37	61	26	31	51	40	52	55		83	66
1971	—	22	10	15	34	14	12	21	10	17	24	16	47	32
1972	—	21	16	10	33	7	11	27	9	9	19	11	53	18
1973	20	31	18	35	58	19	7	29	21	17	23	19	57	57
1974	19	20	13	14	37	13		20	21	9	18	12	57	27
1975	28	23	12	34	40	13		27	27	19	32	21	51	43

Appendix

List of sources and classification for purposes of standardization

SCOTLAND

Edinburgh: 1731–36, 1771–1896. Mossman's compilation from several journals. *Trans R Soc Edin*, **38** and **39** (1896 and 1897).	largely C
Perthshire: Mause (Blairgowrie) 600 ft. 1754–74. MS., author uncertain, at Perth Burgh Library. See also Coates, *Perths Nat Hist Soc*, 1916.	D
Dunkeld (for most part) non-instrumental. M.S journal of James, Duke of Atholl. Nov. 1755–Dec. 1763.	C
Meigle (Coupar Angus) 200 ft, Belmont Castle, 1771–99. MS., (James Stewart-Mackenzie, Lord Privy Seal for Scotland). Private Library, Marquess of Bute. Very well kept.	C
Pitlochry (500 ft). 1804–25, and near Perth 1826–32. MS., (James Ramsey). Meteorological Office Library, Edinburgh.	D
Crieff (about 350 ft). 1865–74. MS. Meteorological Office Library, Edinburgh.	C
Aberdeenshire: Foveran (coastal). 1771–81. MS., (G. Watson of Fiddes). Aberdeen University Library.	D
Aberdeen (about 80 ft ?). 1799–1810. MS., (Prof. Scott). Aberdeen University Library.	C
Aberdeen (town). 1829–41. MS., (G. Innes). Meteorological Office, Edinburgh.	D
Alford (350 ft ?). 1843–46. MS. notes. Meteorological Office, Edinburgh.	C/D
Moray region: Gordon Castle. 1781–1827. In Buchan's paper, *J Scot Met Soc*, **5**, 1880.	generally B
Culloden. 1841–80. Buchan, *J Scot Met Soc*, **7**, 1882, p. 178.	C

Lanarkshire: Cambuslang. 1785–1809. MS., (Revd Dr James Meek). Glasgow University Library.	C
Glasgow (University Observatory). 1886–1921. L. Becker, *Geophys Mem, Met Off*, No. 23, 1925.	D
Kincardineshire: 1804–21. MS., author and location uncertain, believed to have been near Johnshaven. Meteorological Office, Edinburgh.	C+
Berwickshire: Duns. 1846–57. MS. interrupted, some estimates needed. Meteorological Office, Edinburgh.	D

NORTHERN ENGLAND

Yorkshire: Near Dewsbury (250 ft). 1708–40. MS., (W. Elmsall). Archives, Sheffield City Library. Some years doubtful.	mainly D
Halifax (350 ft). 1724–27. MS. letters (Nettleton). Royal Society Library.	D
Sheffield (300 ft). 1734–55. MS., (Dr T. Short). Bodleian Library.	D
Braithwaite (750 ft). 1807–57. MS., (A. Shackleton). Keighley Borough Library.	C+
Westmorland: Kendal (150 ft). 1794–1809. MS., (Jonathan Dalton). Manchester Lit Phil Soc.	D
Kendal (200 ft). 1830–70. MS., (W. Fisher). Meteorological Office Library, Bracknell.	C
Northumberland and Durham: Alnwick (200 ft ?). 1739–46. MS., (D. Hastings), interrupted. British Museum.	D
Newcastle (150 ft). 1802–33. MS., (J. Losh). Newcastle Lit Phil Soc.	C
Durham (340 ft). 1848–1950. University Observatory MS. before 1884. Gaps before 1870 filled by estimation from Wylam (1854–71). Newcastle Lit Phil Soc.	largely C, some B
Sunderland. 1857–1913. *Pub West Hendon Observatory*, 4 (Backhouse).	C+

All later observations abstracted as totals from Meteorological Office publications or the *Journal of the Scottish Meteorological Society*.

Classifications:

Aberdeen University (1876–1947)	B
Mannofield (1951–75)	C
Dundee (1881–1975)	C
Leith (1876–1920)	D
Perth (1903–73)	C
Braemar–Balmoral (since 1880)	mostly C
Marchmont (1886–1948)	C–
Edinburgh (Blackford Hill) 1896–1967. Routine, but very consistent.	on whole D
Glasgow Observatory (1886–1921)	D
Leuchars (1922 onwards) becoming A about 1954	C
Eskdalemuir (1910–75)	A
Dyce (1961–75)	A
Pitreavie (1961–75)	B
Acklington (1945–75)	A
Shields (1876–1923), Tynemouth (1924–75) with Seaham (1873–75)	varying C–B–C–B
Durham (1848–1950) continued by near-by Houghall (1951–69) and Hartburn Grange (1971–75) some B, and early D before 1866. B from 1881 to 1915.	generally C

Equations used for standardization: $A = 1{\cdot}1B + 4 = 1{\cdot}3C + 6 = 1{\cdot}5D + 8$.
Adjustment, approximate, for altitude above 100 ft: add 1·5(D) to 3(A) per 100 ft, for eastern Scotland.
References to relevant papers have been given in the text and bibliography.

551.511.32

BAROCLINIC INSTABILITY IN A REVERSED SHEAR FLOW

By C. N. DUNCAN
(Department of Meteorology, University of Edinburgh*)

SUMMARY

The term 'reversed shear flow' is defined and some properties of a baroclinic wave developing in such a flow are described. A numerical model is used to investigate the structure of a polar air depression which was observed to develop under reversed shear flow conditions.

1. INTRODUCTION

The idea that developing depressions grow by converting potential energy which is available in the mid-latitude baroclinic zone to kinetic energy was first proposed by Margules (1903). Many studies using numerical and analytical models have led to a more detailed understanding of the structure and growth of baroclinic waves (see for example Charney (1947), Eady (1949), Green (1960)). These investigations dealt primarily with occasions when the thermal wind and the progression of the disturbance are in the same direction as this is the usual situation. Occasionally the wind at the steering level, the level at which the wind speed and phase velocity of the wave are equal, is in the opposite direction to the thermal wind. Eady (1949) pointed out that this condition exists in the lower stratosphere and that the wave solutions are very similar to those which he obtained for the more common situation. It is desirable that the thermal wind and steering level wind be parallel, otherwise the efficiency of the baroclinic instability process is reduced, at least when the mean flow is in a steady state.

On the planetary scale in the lower troposphere, mid-latitude westerly winds almost invariably increase with height. However, on the synoptic scale the opposite situation, described here as 'reversed shear flow', occasionally exists. Reversed shear flow is defined as uniform, horizontal flow in which the mean wind at a given level is parallel but opposite in direction to the thermal wind at that level. It may also be defined in terms of a layer if the mean wind and the mean thermal wind are taken to be vertically averaged quantities.

Between Norway and Greenland it is not uncommon in winter for a northerly flow to have a southerly thermal wind, probably owing to the influence of the cold East Greenland ocean current on the western flank of the flow in contrast to the relatively warmer water of the Gulf Stream on the eastern side. In northerly flow over the north-east Atlantic in winter the time required for the lowest 300 mb of the atmosphere to attain a surface-induced temperature gradient is of the order of one day.

This paper discusses the structure of a lower tropospheric disturbance in a reversed shear flow and describes a polar air depression which exhibited the unusual features which result from development under these conditions.

---

* Present affiliation: Institute of Space and Atmospheric Studies, University of Saskatchewan.

2. Necessary conditions and observed structure

Consider a wave-like perturbation embedded in a reversed shear flow. Its motion is such that relatively warm air lies to the left of its path with colder air to the right. Horizontal advection would cause the warm air to move behind the trough so that kinetic energy will be gained at the expense of available potential energy only if ascending motion predominates behind the trough with descending motion in the cold air ahead. This pattern of motion requires low-level mass convergence behind the trough, divergence ahead of the trough and the reverse situation above the level of non-divergence. The effect of the reversed shear flow is to reverse the usual configuration of vertical motion and divergence fields relative to an observer at the surface. Since cold air lies ahead of the trough at low levels the trough will slope forward with height.

If the perturbation is considered in a frame of reference moving with the wind at the steering level there is no difference between frictionless baroclinic development in a reversed shear flow and in a flow in which the thermal wind and steering level wind are in the same direction since, in that frame of reference, there is no horizontal motion of the mean flow at the steering level.

On 10 December 1976 a south-easterly thermal wind was observed, particularly below 700 mb, near the Faeroes, when the mean flow was from the north-west. The 1000–700 mb thickness and selected 850 mb geostrophic winds at 00 GMT (Figure 1) illustrate the large region in which a reversed shear flow existed. A weak trough, which was apparent on the surface analysis (Figure 2), deepened and crossed the Orkney Islands before continuing south-eastwards into the North Sea. The wavelength of this disturbance was 700 $\pm$ 150 km and it moved with a phase speed of 12 $\pm$ 2 m s^{-1}. Unfortunately the distribution of radiosonde observations in this region is such that the disturbance cannot be resolved at upper levels, either temporally or spatially.

The satellite picture shown in Plate I was taken from NOAA 5 at 0951 GMT on 10 December 1976 using the VHRR infra-red channel. The vortex to the east of Scotland, enlarged four times in Plate II, coincides with the observed

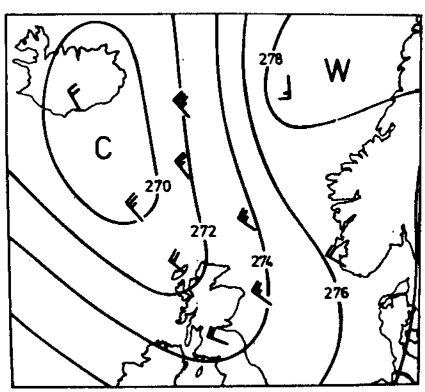

FIGURE 1—THE 1000–700 mb THICKNESS AND SELECTED VALUES OF THE 850 mb GEOSTROPHIC WIND AT 00 GMT ON 10 DECEMBER 1976

Thickness contours are in decametres.

surface trough and indicates large-scale ascent behind the centre of the wave with less-organized, shallower, cumulus convection ahead of the trough. A second vortex lying between Scotland and Iceland is interesting because it does not display this structure. However, no synoptic analysis of this disturbance has been possible since no surface or upper-air observations were made in this area. Furthermore, observations from stations in the Faeroes and the north of Scotland in the subsequent 24 hours showed no evidence of this feature.

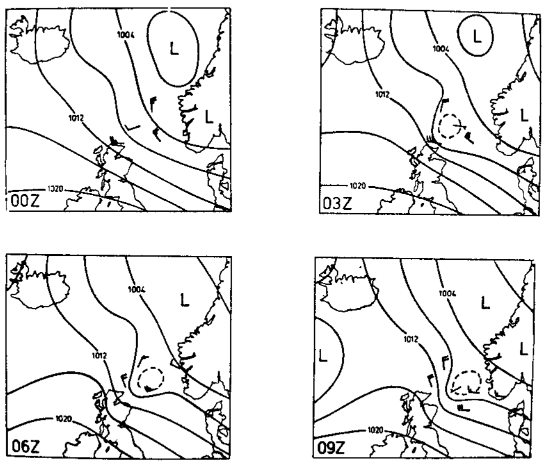

FIGURE 2—SURFACE PRESSURE ANALYSES AND OBSERVED WINDS FROM SELECTED STATIONS ON 10 DECEMBER 1976

3. NUMERICAL STUDY

Normal mode solutions were obtained in a linear, quasi-geostrophic model for growing disturbances which resemble the observed depression in phase speed, growth rate and wavelength when the mean flow parameters correspond to those observed at 00 GMT on 10 December 1976. The model has previously been used to simulate polar low development (Duncan, 1977) and was originally described by Brown (1969). A detailed description of the model will not be given, but it is necessary to state the assumptions which are inherent in its derivation. Horizontal variations in wind speed and static stability are ignored in the mean flow, which is confined to a channel of width 1200 km with horizontal lids at 1000 and 400 mb. The quasi-geostrophic vorticity and omega equations, in linear form, are solved on a two-dimensional grid across the channel. Advection of the earth's vorticity is neglected, as are friction and surface heating and the meridional variation of the Coriolis parameter (β effect). A small, random perturbation at the initial time eventually grows into the most unstable normal mode which would develop under the predetermined conditions of wind and static stability. Solutions are considered to be obtained when the real and imaginary parts of the wave speed are found to vary between grid points by less than 0·05 m s^{-1}.

These assumptions are somewhat restrictive, but the model solutions are intended only as a first approximation to the observed disturbance. The finite channel width is chosen to correspond approximately to the transverse wavelength but the value chosen obviously affects the wavelength of the most unstable wave. Similarly the inclusion of surface heating and friction is important in modelling the development of polar lows although their neglect does not invalidate the use of simple quasi-geostrophic baroclinic waves as a first approximation. A reversed shear flow will usually, although not necessarily, have a greater vertical wind shear in the boundary layer than the more normal flow. This implies an enhancement of the surface fluxes of momentum, heat and moisture. Mansfield (1974), in a study of polar lows, showed that friction and surface heating tend to shift the wavelength of the most unstable baroclinic wave in opposite senses, that both have a damping effect on growth, and that the phase speed of the wave is reduced. In a reversed shear flow the phase speed would increase as a result of the frictional lowering of the steering level.

The mean flow parameters which were employed are given in Table I. Geostrophic and thermal winds were obtained between Stornoway (58°13′N, 06°19′W) and Ørlandet (63°42′N, 09°36′E). By considering radiosonde ascents made at Stornoway, Lerwick (60°08′N, 01°11′W) and Thorshavn (62°01′N, 06°46′W) an estimate was made of the mean static stability profile over the region in which development occurred. Figure 3 shows the vertical temperature structure at these three stations and the temperatures implied by the static stabilities in Table I if a surface temperature of 1°C is assumed.

TABLE I—NUMERICAL MODEL PARAMETERS

$f = 1{\cdot}26 \times 10^{-4}\,s^{-1}$
$\beta = 0\,s^{-1}\,m^{-1}$
Channel width = 1200 km
Horizontal grid length = 100 km
Vertical grid length = 50 mb

Pressure *mb*	Static stability $m^2\,s^{-2}\,mb^{-2}$	Mean flow velocity $m\,s^{-1}$
400 ($\omega = 0$)		
		3·5
500	0·0191	
		5·0
600	0·0175	
		7·5
700	0·0172	
		10·0
800	0·0064	
		12·0
900	0·0047	
		13·5
1000 ($\omega = 0$)		

The most unstable wave identified in the numerical model has a wavelength of 900 km and a phase speed of 10·8 m s^{-1} (Figure 4). It is therefore suggested that the observed disturbance was baroclinic in nature and that its structure was probably similar to that of the 900 km wave in the numerical model. The amplitude and phase of the streamfunction, vertical velocity and thermal perturbations of this wave (Figures 5 and 6) vary with height in a manner which is consistent with the idealized reversed shear flow baroclinic wave described in the previous section. It is particularly interesting that the thermal and streamfunction perturbations are almost in phase except near the steering level.

The rate of conversion of eddy available potential energy to eddy kinetic energy, C(Ae,Ke), and the redistribution of eddy kinetic energy brought about

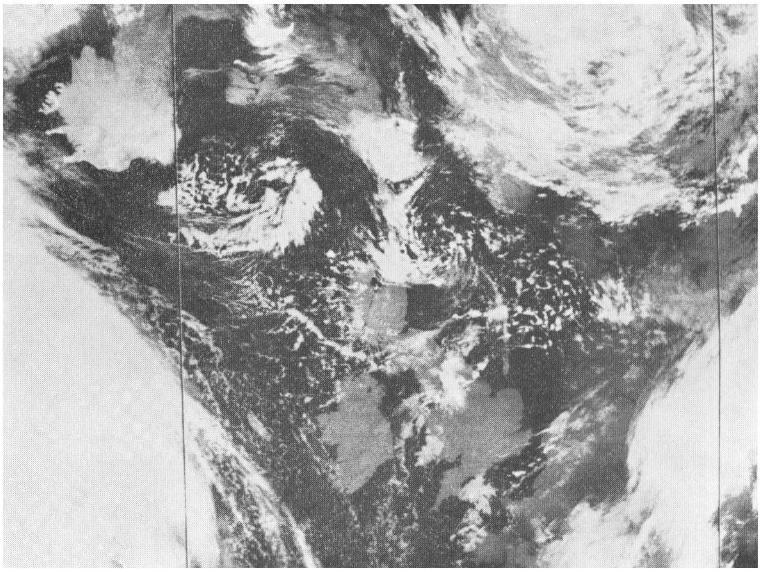

PLATE I—SATELLITE PICTURE FROM NOAA 5 TAKEN AT 0951 GMT ON 10 DECEMBER 1976 IN THE VHRR INFRA-RED CHANNEL

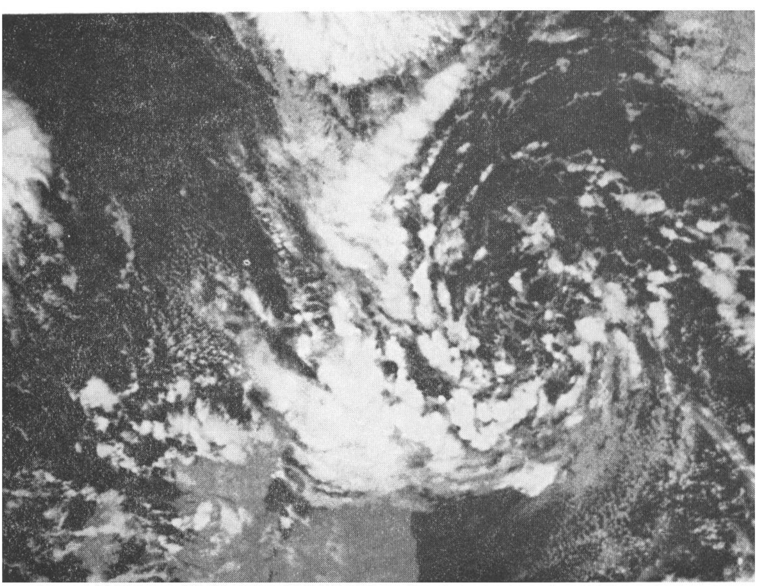

PLATE II— ENLARGEMENT (×4) OF THE VORTEX TO THE EAST OF SCOTLAND IN PLATE I

Photographs by the Department of Electronics and Electrical Engineering, Dundee University

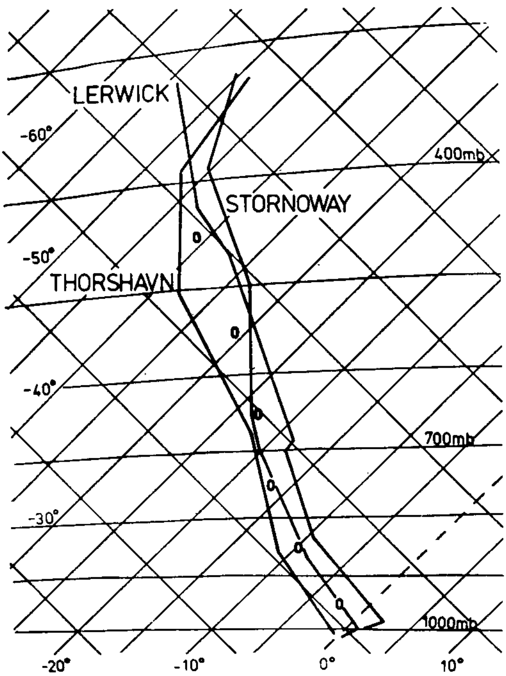

FIGURE 3—TEMPERATURE SOUNDINGS AT LERWICK, STORNOWAY AND THORSHAVN AT 00 GMT ON 10 DECEMBER 1976

Open circles indicate the temperature profile implied by the static stabilities in Table I if a surface temperature of 1°C is assumed.

by the action of pressure forces, not shown, are very similar to those found in previous studies of polar lows (Duncan, 1977). The eddy kinetic energy production due to C(Ae,Ke) is largest at 800 mb and the vertical redistribution of eddy kinetic energy is such that the maximum kinetic energy of the perturbation is found at the surface.

4. DISCUSSION

The development of a low-level trough in a reversed shear flow has been described. In spite of the scarcity of upper-air information the structure of the vertical motion field of this disturbance, illustrated by a satellite photograph, appears to conform to that postulated by consideration of the properties of a reversed shear flow.

It has also been shown that in a simple linear, quasi-geostrophic model the most unstable baroclinic waves which develop under conditions similar to those which existed on 10 December 1976, resemble the observed perturbation in wavelength, phase speed and growth rate. Although friction and surface heating were neglected in obtaining this first approximation it appears that their inclusion would not be inconsistent with the results obtained. When the thermal wind and steering level wind are parallel baroclinic development is possible. Since reversed shear flows are unlikely to extend through great depth in the troposphere the disturbances will be of short wavelength and will be more likely to develop over water surfaces where frictional damping is less.

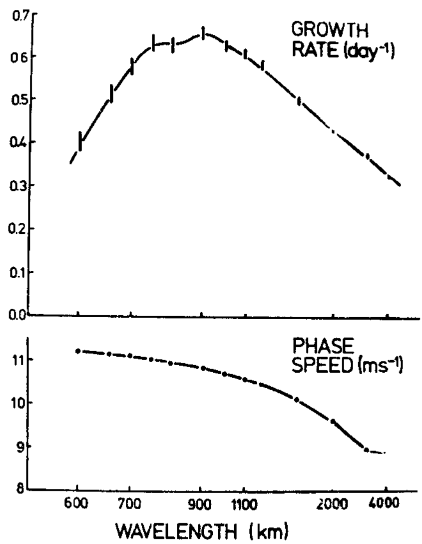

FIGURE 4—GROWTH RATE AND PHASE SPEED AS A FUNCTION OF WAVELENGTH FOR NORMAL MODE SOLUTIONS OBTAINED BY USING THE MODEL PARAMETERS SHOWN IN TABLE I

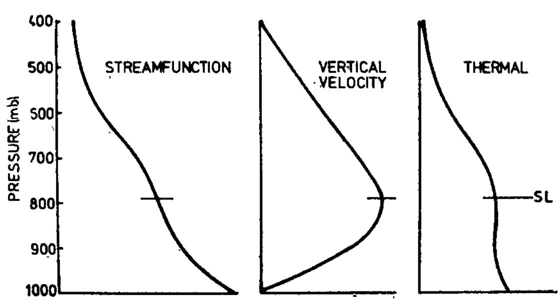

FIGURE 5—VERTICAL PROFILES OF AMPLITUDE OF THE STREAMFUNCTION, VERTICAL VELOCITY AND THERMAL PERTURBATIONS IN THE 900 km WAVE

SL indicates the steering level. The horizontal scale is arbitrary.

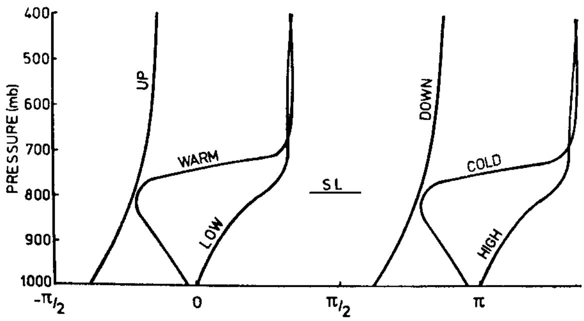

FIGURE 6—PHASE RELATIONSHIP BETWEEN STREAMFUNCTION, VERTICAL VELOCITY AND THERMAL PERTURBATIONS IN THE 900 km WAVE

SL indicates the steering level.

REFERENCES

BROWN, J. A. 1969 A numerical investigation of hydrodynamic instability and energy conversions in the quasi-geostrophic atmosphere. *J Atmos Sci*, **26**, pp. 352–375.

CHARNEY, J. G. 1947 The dynamics of long waves in a baroclinic westerly current. *J Met*, **4**, pp. 135–162.

DUNCAN, C. N. 1977 A numerical investigation of polar lows. *Q J R Met Soc*, **103**, pp. 255–267.

EADY, E. T. 1949 Long waves and cyclone waves. *Tellus*, **1**, pp. 33–52.

GREEN, J. S. A. 1960 A problem in baroclinic instability. *Q J R Met Soc*, **86**, pp. 237–251.

MANSFIELD, D. A. 1974 Polar lows; the development of baroclinic disturbances in cold air outbreaks. *Q J R Met Soc*, **100**, pp. 541–554.

MARGULES, M. 1903 Über die Energie der Stürme. *Jahrb Zentralanstalt Met, Wien*, pp. 1–26.

551.508.762

THE MK 3 CLOUD BASE RECORDER—A REPORT ON SOME OF THE POTENTIAL ACCURACY LIMITATIONS OF THIS INSTRUMENT

By H. A. DOUGLAS* and D. OFFILER

(Meteorological Office, Bracknell)

SUMMARY

For the last nine years nodding-beam cloud-base recorders have been in operational use as an aid to observers, and there are currently some 80 such instruments in service in the UK Meteorological Office. No official document on the expected limitations on the accuracy of this instrument was ever issued but several users have suspected that it systematically underestimates the height of the cloud base. A theoretical error analysis supports such a hypothesis and gives an indication of the possible magnitude of such an error. Evidence from two field trials is presented which qualitatively agrees with the theoretical analysis but shows that the theoretical interpretation does not yet account for all the apparent differences obtained in practice. A new balloon-borne device for identifying cloud base, with which it is hoped to establish the limits of uncertainty, is described.

* Now at Meteorological Office, RAF Strike Command, High Wycombe.

1. Introduction

In 1968 the current design of the UK Meteorological Office Cloud Base Recorder (Mk 3 CBR) was introduced into operational service as an aid to observers at airfield sites. The main advantage of the Mk 3 CBR (described briefly in section 2) over the cloud searchlight was that it could operate in daylight. As with any new instrument, a full test program was carried out before its introduction. The instrument was designed so that any bias in the system would tend to give a low height indication, thus erring on the side of safety. At the time of the introduction of the Mk 3 CBR its limitations and design principles were explained to the user, but no document gave details or an indication of the possible errors.

In 1973 a theoretical study was undertaken (Painting and Williams, unpublished internal report) of these effects and some of the conclusions are presented in section 3. A study (National Weather Service, 1971*) was also undertaken in the United States of America with similar results. Independently of these studies, observers and others working with the instrument in the field began to suspect a systematic difference between its readings and other estimates of the height of the cloud base, and initiated their own investigations. The results of two such investigations are presented in section 4, and the evidence supports the conclusion of the theoretical approach.

As part of an evaluation and development program intended to lead to proposals for a replacement for the Mk 3 CBR, a Cloud Height Remote Indicating System (CHRIS) has been developed to help establish the limits of uncertainty inherent in the Mk 3 CBR. The operating principles of CHRIS are briefly introduced in section 5.

2. The Mk 3 CBR—theory of operation

The Mk 3 CBR uses the simple laws of trigonometry as applied to right-angled triangles. A transmitter unit, by opto-mechanical means, produces a 1 kHz pulsed beam of light which scans through a vertical sector of the sky. The rate of the scan is controlled by a drive-cam shaped so that the rate of change of height of the beam above the receiver is nearly constant over its full range. The receiver unit, at a fixed known distance (350 ft) from the transmitter, accepts scattered light from vertically above itself, and a phase-sensitive detector is used to identify any return from the transmitter unit. At all times the position of the pen arm on the recorder unit is related to the angle of the transmitter beam by means of a magslip† transducer. When the receiver identifies a return, the chart is marked appropriately. One scan (i.e. one upsweep and one downsweep) over the height range 100–4000 ft takes about one minute.

---

* Washington, U.S. Department of Commerce, National Oceanic and Atmospheric Administration, National Weather Service. Evaluation of Common Ceilometer Technology. *NOAA Tech Mem NWS T & EL* 13, 1971.

† A magslip is a commercially produced device for relaying angular motions in a precise way.

3. Theoretical consideration of possible error sources

(a) *General*

When considering the design of the Mk 3 CBR, possible sources of error were identified as belonging to one or more of the following features:

(i) The 2° beamwidth of the transmitted beam and the 2° acceptance angle of the receiver.
(ii) The magslip alignment.
(iii) The optical alignment.
(iv) The function cam.
(v) The receiver electronics.
(vi) The base line accuracy.

Each of these features will be considered in turn, and in each case the 'error' will be related to the 'indicated height' (i.e. the height as actually recorded by the Mk 3 CBR).

(b) *Beamwidth error*

The principle of this error is illustrated by Figure 1. The receiver unit's cone of acceptance is the triangle ARB, whilst the transmitted beam is given by triangle ATZ and the cloud base is assumed to be horizontal. The point Y is the intersection of the centre lines of the transmitted beam and the angle of acceptance of the receiver. The receiver responds to light scattered by the cloud, and thus in the limiting case (as illustrated by Figure 1(a)), the receiver identifies cloud when the leading (on the upsweep) or trailing (on the downsweep) edge is at A. In this case, whilst the true height is 'h_1', the instrument only indicates a height of 'h' (see Table I). Figure 1(b) illustrates the ideal case, in which the sensitivity is such that the receiver 'sees' cloud at the precise instant at which point Y is coincident with the cloud base—and in this case there is no error. This is also the position of maximum return signal, and thus if the instrument indicates a cloud base at a height of 'h', the true height must lie between 'h_1' and 'h'. As it is important not to miss an indication of cloud, and as the cloud may have varying droplet density distributions each implying a different scattering function, the sensitivity, which remains constant throughout the scan cycle, is set between the limits illustrated by Figures 1(a) and 1(b). As it is difficult to estimate the 'typical' setting accurately, a value mid-way between 'h' and 'h_1' (see Table I) has been taken to represent the uncertainty due to beamwidth and the acceptance angle of the receiver.

Table I—Estimation of the errors due to beamwidth

Height as indicated by CBR *ft*	Maximum true height while within tolerance *ft*	Maximum difference (indicated minus true) *ft*	Expected difference (half maximum) *ft*
100	107	−7	−4
250	263	−13	−7
500	533	−33	−17
1000	1117	−117	−59
1500	1771	−271	−136
2000	2505	−505	−253
3000	4288	−1288	−644
4000	6663	−2663	−1332

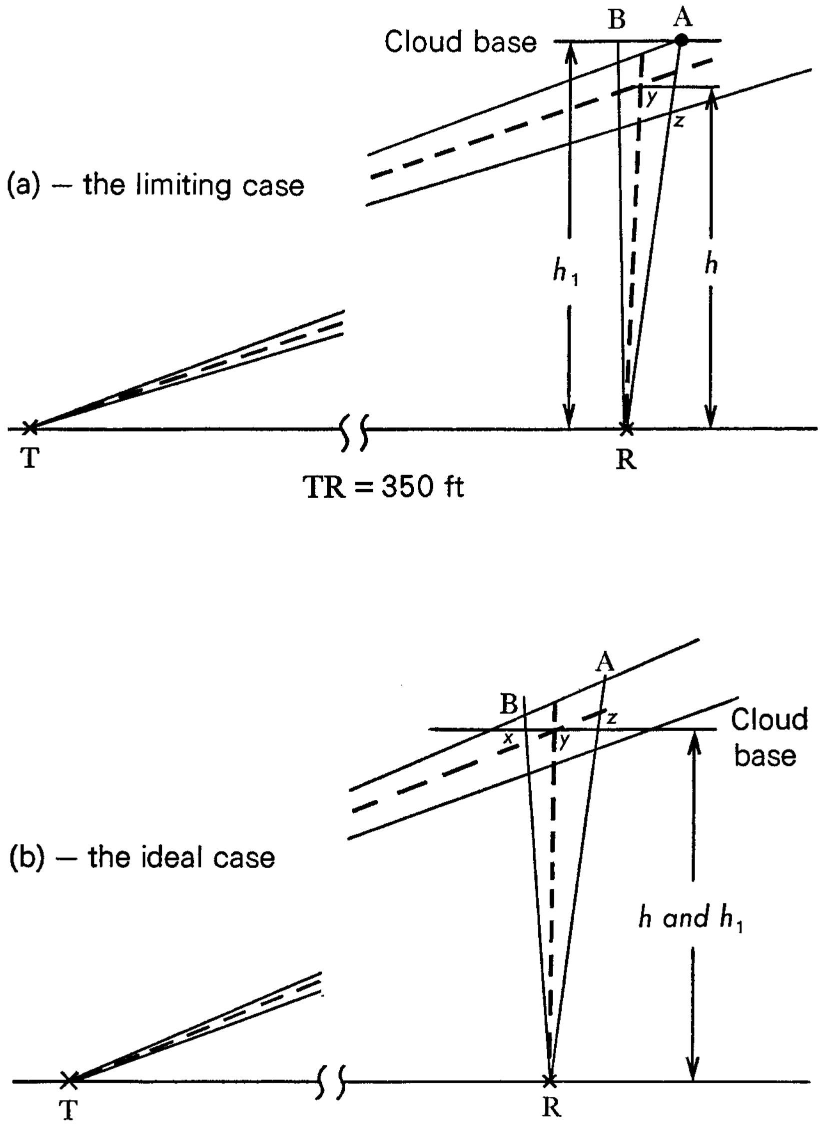

FIGURE 1—DIAGRAM SHOWING THE RELATIVE GEOMETRIES OF THE TRANSMITTED BEAM AND THE CONE OF ACCEPTANCE OF THE RECEIVER OF THE UNITED KINGDOM MK 3 CLOUD BASE RECORDER

In (a), the limiting case, the errors due to beam spread are at a maximum.
In (b), the ideal case, there is no error due to beam spread.
– – – centre of transmitted beam and cone of acceptance
—— limits of transmitted beam and cone of acceptance
h_1 true height of cloud base
h indicated height of cloud base

In this as with all these estimates, the instrument is assumed to be operating within the normal tolerances laid down for installation and routine maintenance.

(c) *Optical alignment*

The main optical components can be set to a high degree of precision and thus the most critical feature is the accuracy with which the lamp filament can be positioned, since small errors in this setting have the effect of an angular beam misalignment. An error of 1 mm is possible; this is equivalent to an angular error of 0·5°, and the result of such an error is indicated in Table II.

TABLE II—ESTIMATION OF THE ERRORS ASSOCIATED WITH A 0·5° MISALIGNMENT OF THE ANGULAR BEAM

Indicated height (ft)	100	250	500	1000	1500	2000	3000	4000
Difference (ft)	±3	±5	±10	±29	±62	±106	±231	±402

(d) *Magslip alignment*

The best possible setting, in operation, of the two magslip units is equivalent to 0·25° and thus the errors will be half those indicated in Table II. By the nature of its design the receiver element of the magslip unit (in the recorder) will always be trying to follow that of the transmitter element (in the transmitter). The difference in their settings at any instant is a measure of the error and is related to any acceleration in the transmitter unit. The use of cams makes such additional magslip errors negligible.

(e) *Function-cam and base-line errors*

Compared with the previous errors these can be neglected, but they are listed here for completeness. The error due to the function cam would not exceed 0·25 per cent of the indicated height and thus the error at 4000 ft would be less than 10 ft. An error in the base line, say of 3 ft—an extreme case—would only give an error of 35 ft at 4000 ft and about 8 ft at 1000 ft.

(f) *Receiver electronics*

This is a difficult area in which to assess the uncertainty or error. The major source of uncertainty will be associated with the performance of the phase sensitive detector and in particular the time taken to 'recognize' a return signal. The various factors which would contribute to an overall uncertainty figure have never been systematically investigated and such an investigation has not yet been warranted. Thus no figures will be included for receiver electronics errors although, in practice, there will be such an error, perhaps of a similar magnitude to that of the optical alignment error. For comparison, Table III shows the error caused by a 250 ms delay (the maximum delay measured during trials) in 'recognizing' a return signal.

TABLE III—ESTIMATION OF THE ERROR ASSOCIATED WITH A 250 ms DELAY IN 'RECOGNIZING' A RETURN SIGNAL

Indicated height (ft)	100	250	500	1000	1500	2000	3000	4000
Difference (ft)	±5	±7	±14	±42	±89	±154	±344	±603

(g) *Implications of the theoretical study*

The errors listed above are all independent, and apart from that of 3(b), will give a zero mean error when considered over a large number of observations and installations. The beamwidth error is, of necessity, single-sided and is in practice the most likely cause of the largest error. Table IV shows the aggregate of the errors and is expressed in the form of an expected true height (for each selected indicated height) as a result of the beamwidth error, and a standard deviation σ where $\sigma = (\Sigma\sigma_r^2)^{\frac{1}{2}}$ and $\sigma_r (r = 1 \ldots n)$ is the standard deviation of each of the other errors. The σ_r are deduced on the assumption that these errors are distributed normally with extreme values of $5\sigma_r$. These results are indicated in Figure 2 which shows the beamwidth error and uncertainty bars (2σ) at the selected heights.

It should again be emphasized that the standard deviation does not include a true allowance for the receiver electronics error (only the delay error is included), and thus Figure 2 should be taken only as a rough indication of the likely error in any reading taken from a Mk 3 CBR chart.

TABLE IV—SUMMARY OF THE EXPECTED ERRORS DUE TO BEAMWIDTH, AND THE STANDARD DEVIATIONS OF OTHER ERRORS FOR SOME SELECTED INDICATED HEIGHTS

Indicated height *ft*	Expected true height *ft*	Standard deviation of the expected height (due to errors other than beamwidth) *ft*	Indicated height minus expected height *ft*
100	104	1·25	−4
250	257	1·9	−7
500	517	4	−17
1000	1059	11	−59
1500	1636	23	−136
2000	2253	39	−253
3000	3644	86	−644
4000	5332	150	−1332

4. SOME EXPERIMENTAL OBSERVATIONS

Whilst the Mk 3 CBR has been in operational use, forecasters and meteorological observers have made their own comparisons with other sources of information; at some stations, on their own initiative, they have conducted detailed comparisons between observations from other sources and the values obtained by the Mk 3 CBR. The results of two of these comparisons are presented here to illustrate the nature and magnitude of the results.

During 1975 the staff at Liverpool Airport undertook a comparison between a cloud searchlight (maximum errors due to all sources but with the instrument correctly adjusted as described in the Handbook of Meteorological Instruments, Part I are given in Table V) and a Mk 3 CBR sited some 800 ft from the searchlight. The results, for those heights having enough data, are given in Table VI, and the points are indicated in Figure 2.

TABLE V—ESTIMATION OF THE MAXIMUM ERRORS WITH A CLOUD SEARCHLIGHT, CORRECTLY ADJUSTED, AND ASSUMING A UNIFORM CLOUD BASE

Indicated height (ft)	100	250	500	1000	1500	2000	3000	4000
Maximum error (ft)	±17	±18	±22	±35	±57	±87	±175	±297

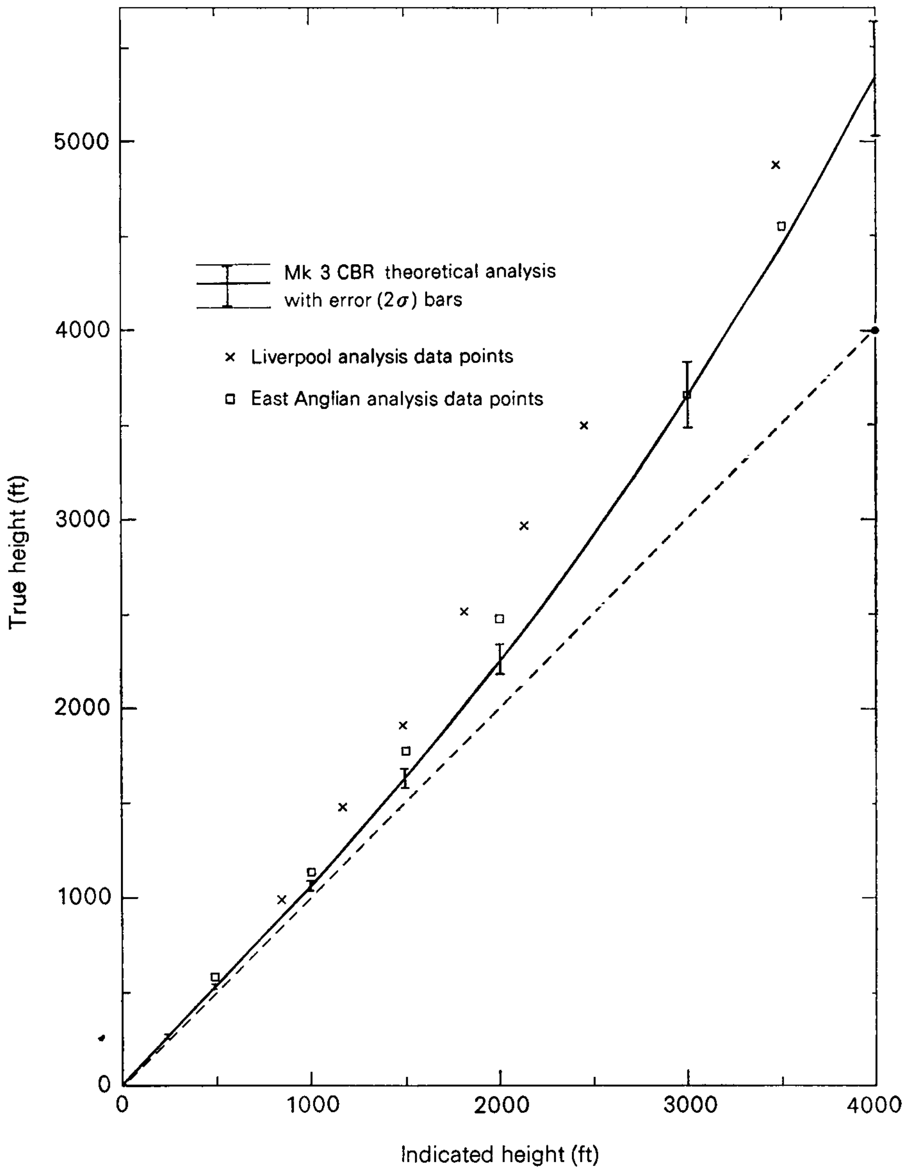

FIGURE 2—VISUAL PRESENTATION OF THE DATA IN TABLE IV SHOWING THE MAGNITUDE OF THE EFFECT OF BEAM SPREAD

The results from the two investigations at Liverpool and in East Anglia are plotted for reference. The dashed line corresponds with zero height error.

TABLE VI—SUMMARY OF THE RESULTS FROM THE LIVERPOOL AIRPORT TRIAL

Indicated height (ft)	850	1170	1490	1810	2130	2450	3465
Mean error (CBR minus searchlight) (ft)	−113	−370	−422	−694	−832	−987	−1392
No. of observations	53	30	50	36	52	24	26

The second example is from an investigation carried out at several sites in East Anglia over the period 1973–75. The comparison values were based on cloud-searchlight observations, pilot-balloon ascents and cloud heights reported by pilots. Over 500 observations were made in this study, and some of the results are given in Table VII, the corresponding points again being indicated in Figure 2.

TABLE VII—SUMMARY OF THE RESULTS FROM THE EAST ANGLIAN TRIAL

Indicated height (ft)	500	1000	1500	2000	3000	3500
Mean error (CBR minus check) (ft)	−80·5	−156	−288	−486	−650	−1053
No. of observations	36	32	60	65	31	47

Both these studies illustrate the same trend as is indicated by the theoretical study. The Liverpool comparison is systematically higher than either the East Anglian comparison or the theoretical indication. That the three studies do not agree numerically does not mean that any one study is right or wrong. Both the experimental results are higher than the theoreal and thus it could be argued that a value other than half the maximum beamwidth error should have been used. Also not all aspects of the Mk 3 CBR were taken into account and this may have some bearing on the results, and finally we do not have detailed knowledge of the performance details of the CBRs at all stages of the comparisons. Nevertheless, the three studies taken as a composite group offer strong evidence that the Mk 3 CBR systematically reads low by the level of magnitude indicated in Table IV.

5. CARDINGTON TRIAL

Part of the trials program to establish a replacement for the Mk 3 CBR will take place at the Meteorological Research Unit (Cardington) where a balloon-borne package can monitor the base of a cloud layer whilst a Mk 3 CBR operates in the vicinity. A Cloud Height Remote Indicating System (CHRIS) has been developed (Offiler, unpublished internal report), based on a series of water-content detectors spaced at 10 m intervals, and a package providing pressure and temperature (and thus height) which can be mounted on the Cardington balloon cable, the data being transmitted to a data-logging system on the ground (Figures 3 and 4).

The system was tested at Cardington, using a double theodolite system as the standard with which to measure the height of the probe, and based on these trials CHRIS was expected to measure the cloud base to within ±15 m (10 m for height error from pressure and 5 m because of the probe separation), except when the base was diffuse and therefore difficult to define to this degree of precision.

The equipment is now awaiting use during the main CBR trials program.

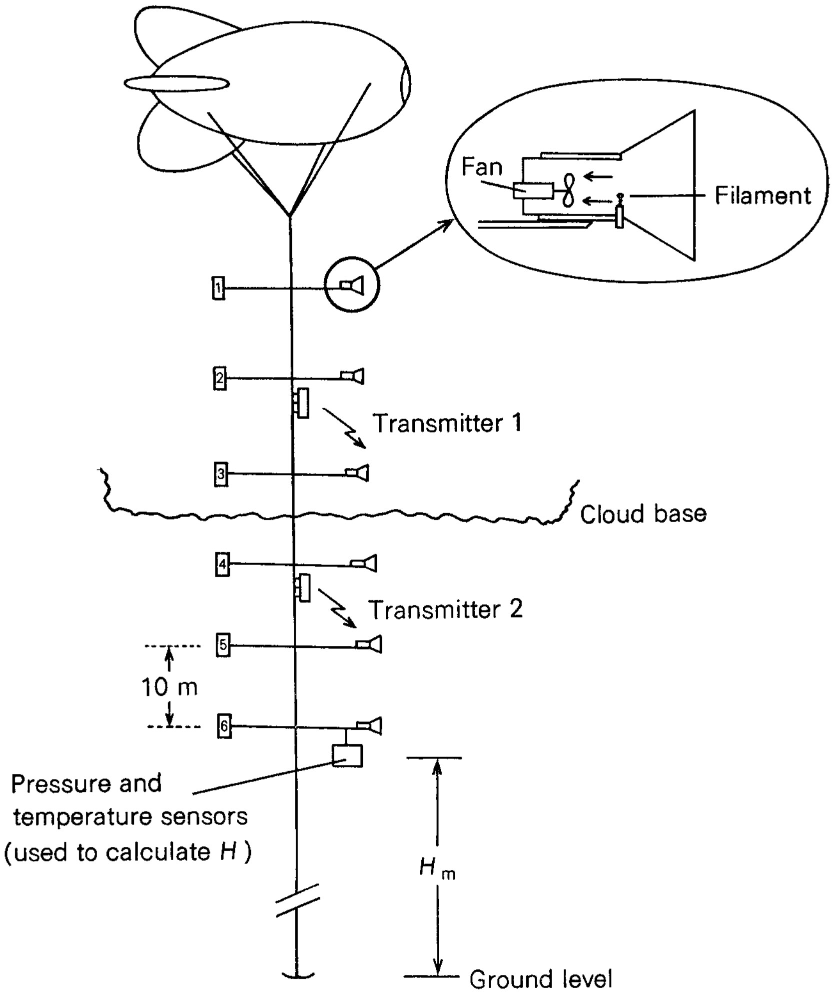

FIGURE 3—CLOUD HEIGHT REMOTE INDICATING SYSTEM (CHRIS)

A schematic view illustrating the procedure for a cloud-base mid-height amongst the array. The insert shows the probe head in schematic form.

6. CONCLUSIONS

This paper provides both theoretical and experimental evidence that the current Mk 3 CBR reads systematically low and Table IV provides an indication of the likely magnitude of the deviations. It should be noted that the errors for heights below about 1000 ft are relatively small. A problem in assessing any instrument designed to measure the height of the cloud base is the difficulty of defining

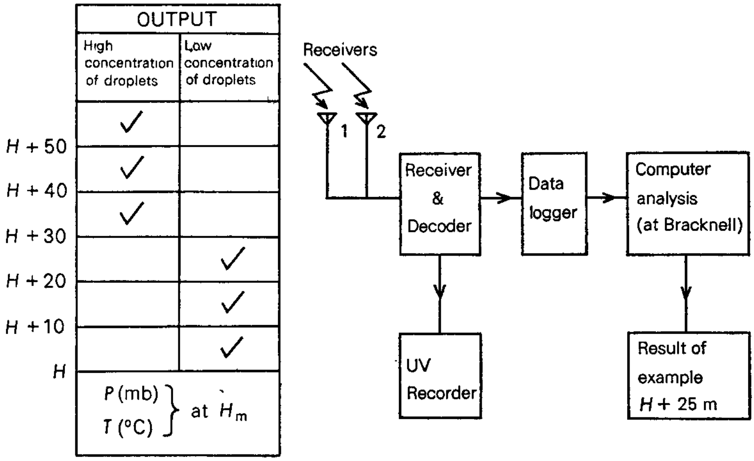

FIGURE 4—BLOCK SCHEMATIC FURTHER ILLUSTRATING THE PROCEDURE FOLLOWED IN FIGURE 3

the cloud base and a system has been developed and tested which should help to establish the relationship between the step-function in the water-content distribution near a cloud base and the height of the base as recorded by the CBR. Such information will provide an independent assessment of the height accuracy of the Mk 3 CBR.

7. ACKNOWLEDGEMENT

The authors wish to acknowledge their appreciation of the work and effort of all colleagues who have in any way provided data for this paper.

REVIEW

Climate: Present, past and future. Volume 2, Climatic history and the future, by H. H. Lamb. 235 mm × 180 mm, pp. xxx + 835, *illus.* London, Methuen; New York, Barnes & Noble, 1977. Price: £38.

When Professor Lamb tackled the writing of this authoritative book on climatic changes he undertook a monumental task. Volume 1 appeared in 1972, and Volume 2, which has now been printed, is even more impressive in its scope and the extent of its survey of the literature.

The plan which Professor Lamb adopted was a good one. Volume 1 was to contain a survey of the fundamentals of climate—the general circulation of the atmosphere and the physical mechanisms involved—together with a description of world climate as it is now. Volume 2 was to provide the climatic history and a look into the future. Separate chapters would discuss the sources of evidence on past climates, their techniques and validity, and subsequently piece together the evidence for pre-Quaternary, Quaternary, post-Glacial, Historical and the Instrumental periods. Rather unfortunately Professor Lamb must have found it difficult to adhere to his plan. Climatic change is a rambling subject in which many threads of evidence are drawn together, and Professor Lamb has been unable to resist a temptation to follow each thread, once started, far beyond the scope of the chapter as implied by its title. The result is a great deal of repetition, and a book which is longer than it need be. The task of the reader is also not made easier by a plethora of parentheses and footnotes, or by the long and involved sentence constructions.

However, the book collects together an enormous amount of information relevant to past climates. Some of it is very valuable—particularly some of the tabular matter, which runs to over 100 pages—and some of it is intriguing rather than significant—for example, the association between the average age of marrying and the mean annual temperature (p. 264).

The scientific community will undoubtedly welcome the timely publication of Professor Lamb's Volume 2 as giving a broad survey under one cover of a very diverse and scattered literature. The extensive references will be greatly appreciated and will form the starting point for many further researches. The explanations of the specialist terms and nomenclature of geologists, historians, limnologists, stratigraphers, archaeologists and others will be exceedingly welcome to meteorologists trying to understand a paper in a relevant but unfamiliar discipline. The comprehensive index will also be valued.

Much of the 'proxy' evidence of past climates is of doubtful validity. Professor Lamb weaves his way through the mass of material, rarely challenging the interpretation placed on it by the original authors. Often, however, he interpolates an interpretation of his own in terms of the atmospheric circulation, 'dust veils', or solar variations. Clearly many of these ideas have not been subjected to rigorous scientific assessment—it would not have been practicable to do so—and they may ultimately prove wrong. Nevertheless one must not belittle the role of intelligent guessing in this subject, where a coherent picture of events is built by the patient collection of many clues which in themselves have little significance. Indeed, ideas on ice-ages and continental drift were first built up on scanty and speculative evidence, but subsequently received incontrovertible and quantitative confirmation from isotope ratios and palaeomagnetic measurements.

Compared with the comprehensive treatment of the past, Professor Lamb's treatment of the present and future is far less thorough. The present is dealt with in Volume 1 mainly as a background to the understanding of climatic change. The future is included in Volume 2 mainly, one feels, for the sake of completeness. Chapter 19 on 'Man-made climatic changes' gives a general survey of the subject without any quantitative discussion in depth of the mechanisms which may, or may not, be important. Chapter 20 on 'Approaches to the problem of forecasting' makes some useful points about the way in which scientists should answer questions about future climate, but one is left uncertain as to whether the author considers that any real forecasts should be given (other than probabilities based on past statistics). An appendix gives 24 different climatic forecasts from various sources and they are compared with subsequent events to date. There are some which seem to have a germ of success. How far they have been selected because of this one cannot know, but they do seem to show that informed scientists have been able to do better than the indefinite extrapolation of trends which has often been popular—upward for temperature in the first half of this century and downward since.

Professor Lamb has certainly produced a book that will be a classic in its subject.

J. S. SAWYER

NOTES AND NEWS

Association of British Climatologists—New Directory

The Association of British Climatologists, which now forms the Specialist Group in Climatology of the Royal Meteorological Society, is preparing for publication a Third Directory of British Climatologists. Although direct contact will be made with all who appeared in the Second Directory, it is hoped that as many climatologists as possible (whether included previously or not) will write to Professor S. Gregory, Department of Geography, University of Sheffield, Sheffield S10 2TN, before the end of January 1978 for further information about inclusion.

The 15th International Conference on Alpine Meteorology (ITAM-78)

The 15th International Conference on Alpine Meteorology (ITAM-78) will be held in Grindelwald (Bernese Oberland, Switzerland) from 19 to 23 September 1978. The main subjects to be dealt with will be the influence of mountains on the weather and climate, and specific meteorological and climatological phenomena observed in mountain areas.

Those wishing to give papers at this meeting should send the title and a short summary of their proposed contributions not later than 31 January 1978 to the following address, from where further information can also be obtained:

Swiss Meteorological Institute
ITAM-78
Krähbühlstrasse 58
CH-8044 Zurich
Switzerland.

The telephone number of the Swiss Meteorological Institute is

01/34 67 20

and its Telex number is

52202.

Retirement of Mr D. G. Harley

With the retirement of Mr D. G. Harley, Assistant Director (International and Planning) on 13 December 1977 the Office has lost another of the small remaining band of pre-war entrants. Those of us who have known him and worked with him over the years will miss his cheerful presence in our ranks.

David Harley graduated from Edinburgh University in 1938 with honours in physics and entered the Office in October of that year. After some initial training (no Shinfield Park in those days!) he was soon involved in forecasting on RAF stations and was posted to Gibraltar in 1940. He was commissioned as Flight Lieutenant in the RAFVR in 1942 and returned to the United Kingdom in 1943 for further service with the Royal Air Force. Mr Harley received a Mention in Dispatches in 1944.

There followed a rather special assignment when Mr Harley joined in 1946 the small unit in Lisbon which throughout most of the war discreetly served British civil aircraft flying in and out of Lisbon. He was demobilized during that time and when he left Lisbon in 1948 there began a long period of civil aviation work both at London Airport and at Prestwick in his native Scotland. Mr Harley soon established himself as a shrewd forecaster with special experience of Atlantic problems and he was appointed Senior Meteorological Officer at Prestwick in 1960.

In 1964, by which time he was working in the new Headquarters at Bracknell, Mr Harley visited the West Indies to report, in consultation with the Director of the Caribbean Meteorological Service, on the meteorological requirements of the British Windward and Leeward Islands and British Guiana.

Mr Harley joined the International and Planning Branch (Met O 17) in 1964 and on promotion to Senior Principal Scientific Officer in 1967 was appointed ADMetO(IP), the post from which he retired. During his ten years of international work he acquired a comprehensive knowledge of the ramifications of WMO and his advice was frequently sought by members of the Directorate involved in the work of the various WMO bodies. He naturally became widely known internationally and was greatly respected and liked for his integrity and understanding. Partly as a result of his Chairmanship for a time of the WMO Executive Committee Working Group on Antarctic Meteorology he visited the USA Antarctic Expedition bases in 1969 as Official British Exchange Representative.

David Harley has a bright, lively mind with wide interests and to those who know him well there seems little likelihood that he will stagnate in retirement.

We wish Mr and Mrs Harley a long and happy retirement.

G. A. CORBY

THE METEOROLOGICAL MAGAZINE

NO. 1266 JANUARY 1978 VOL. 107

CONTENTS

NOTICES

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

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

Complete volumes of 'Meteorological Magazine' beginning with Volume 54 are now available in microfilm form from University Microfilms International, 18 Bedford Row, London WC1R 4EJ, England.

Full size reprints of out-of-print issues are obtainable from Johnson Reprint Co. Ltd, 24–28 Oval Road, London NW1 7DX, England.

Issues in Microfiche starting with Volume 58 may be obtained from Johnson Associates Inc., P.O. Box 1017, Greenwich, Conn. 06830, U.S.A.

Printed in England by Heffers Printers Ltd, Cambridge
and published by
HER MAJESTY'S STATIONERY OFFICE

£1 monthly **Annual subscription £13.14 including postage**

Dd. 497684 K15 12/77

ISBN 0 11 724795 2
ISSN 0026–1149