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OCEAN WEATHER SHIPS

BY COMMANDER C. FRANKCOM, R.N.R.

History.—Prior to the year 1936, synoptic observations from the sea were provided almost entirely by voluntary observers in merchant ships, apart from those obtained from the relatively small number of naval vessels. These observations, although extremely valuable to the forecaster, were necessarily restricted in nature, and more or less haphazard as regards position.

As transoceanic aircraft became a possibility, it became obvious that more detailed information was necessary than could be obtained from voluntary observers in moving ships in order to provide meteorologists and aircraft with accurate information about weather conditions at sea, both on the surface and in the upper atmosphere.

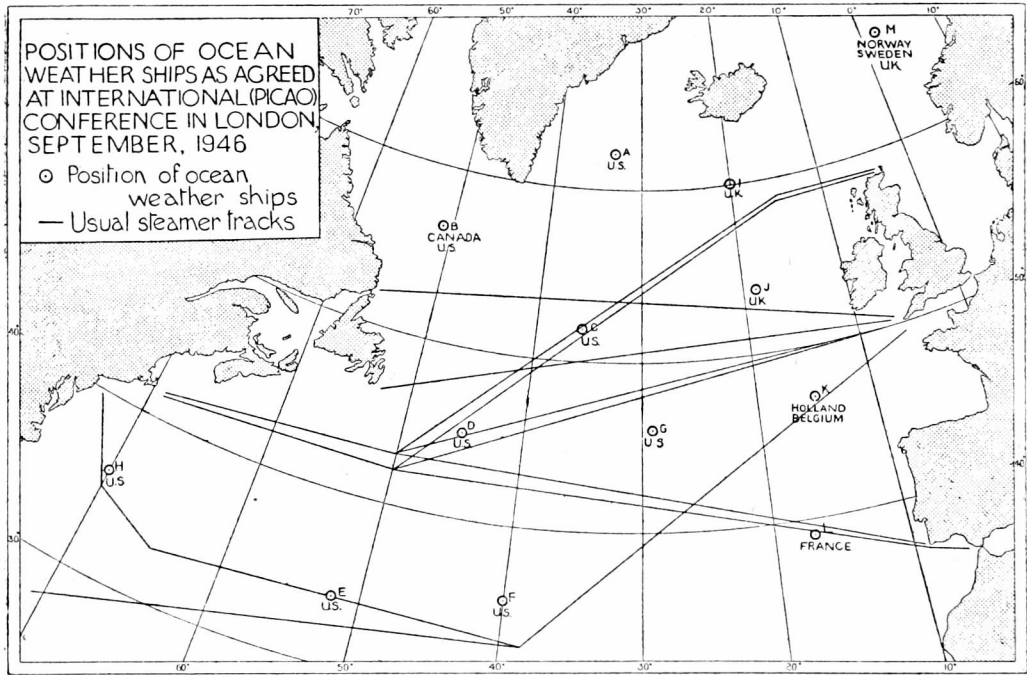
In 1936–7, the British Meteorological Office placed a meteorologist aboard a cargo steamer on the North Atlantic trade route during several voyages and obtained a regular series of special synoptic observations as an experiment. Visual observations of cloud heights and of upper winds were obtained in this ship by the use of pilot balloons.

In 1938–9, the French Government fitted up the merchant vessel *Carimaré* as a stationary meteorological ship in the North Atlantic. Observations of conditions in the upper atmosphere by radio-sonde were successfully obtained in this ship as well as those of surface conditions, and the results transmitted by radio. At about the same time, the Germans had two special vessels performing similar functions in connexion with their transoceanic airways—one operating in the North Atlantic and the other in the South Atlantic. The British Meteorological Office was exploring the possibility of fitting up a vessel specially for this type of work in the summer of 1939.

The war of 1939–45 put an end to all the above activities, and in the early part of that war observations from the oceans were only obtainable from naval vessels and from aircraft. As the war progressed, both sides used various

ingenious methods to obtain weather observations from the oceans for their own use. In the latter part of the war, owing to the large number of Allied aircraft regularly crossing the Atlantic, the United Kingdom and United States authorities employed a number of small naval vessels as stationary meteorological ships in that ocean.

When the war finished, the naval stationary vessels were gradually withdrawn, and observations were once more obtainable from merchant vessels. It was realised however, that such observations were not sufficient, and early in 1946 the Conference of Directors of the International Meteorological Organization at a meeting in London passed a resolution urging the establishment of stationary meteorological ships in certain ocean areas. Shortly afterwards, the Provisional International Civil Air Organization (PICAO) passed a similar resolution in Dublin. In the summer of 1946, at a meeting of the member states of PICAO in London, it was agreed that a total of 13 stationary meteorological ships would be established in the North Atlantic by July, 1947.



The PICAO Agreement.—The United States, Canada, France, Holland, Belgium, Norway, Sweden, Great Britain, Eire, Denmark, Iceland, Portugal and Spain were all signatories to the “Ocean Weather Ship” agreement. It was agreed that the allocation of stations would be as follows :—

United States	7
Canada and United States, jointly		1
France	1
United Kingdom	2
Norway, Sweden and U.K. jointly		1
Holland and Belgium, jointly	..	1

Eire agreed to provide an annual monetary contribution towards the scheme. It was decided that Portugal, Denmark and Iceland already contributed

sufficiently to the safety of transoceanic aircraft by the establishment of meteorological stations in the Azores, Greenland and Iceland respectively.

It was decided that on an average it would need at least two ships to maintain one ocean weather station. The minimum size vessel which could satisfactorily perform the necessary duties was considered to be one of about 1,300 tons displacement, having a length of about 200 ft. and being of a suitable type for North Atlantic work.

The duties of the ship would include :

(a) *Meteorological observations*.—Surface observations every three hours.

Special observations, when necessary, of meteorological phenomena and of important changes in the weather.

Upper air wind observations by radar methods not less than four times daily.

Upper air temperature, pressure and humidity by radio-sonde not less than twice daily.

All the above observations would be reported by radio at the appropriate international hours. In addition, observations from certain merchant ships and other ocean weather ships would be collected and re-transmitted by radio.

(b) *Search and Rescue Services*—for aircraft and shipping in distress, as necessary, for which the requisite equipment will be provided aboard the ships. This implies the provision of special boats and other life-saving equipment, radar and special radio equipment, including beacons on which aircraft can “home”. The general scheme is that aircraft in distress can “home” on the ocean weather station and alight near enough for a rescue to be effected.

(c) *Navigational aids to aircraft in flight*, for which special radio beacons will be fitted aboard the ships.

(d) *Oceanographical and other scientific observations* as far as it is practicable.

The attached map shows the agreed distribution of the ocean weather stations, together with an approximation of the usual transatlantic steamer tracks. It should be emphasised that the establishment of these ocean weather stations will not in any way lessen the importance of observations from merchant ships. The network of observations from the oceans can never approach the density obtainable from stations ashore, but the closer the density the more able is the meteorologist to forecast coming weather changes. The ocean weather ships will merely approximate to islands from which regular observations, both on the surface and in the upper air, are obtainable—the immense gaps being filled in by observations from merchant vessels. It is hoped that the establishment of these stations will not only further the safety of transoceanic aircraft and shipping, but that they will also be the means of greatly improving the accuracy in forecasts for the benefit of the whole community.

The British plan for the operation of their two stations is to employ four ex-naval corvettes of the “Flower” class. These vessels are about 200 ft. in length, are built on whaler lines and have a loaded displacement of about 1,400 tons. They are oil-fired steam vessels, having reciprocating engines and a single screw, and a maximum speed of about 16 knots, economical

speed 9 knots. They have established a reputation for being excellent sea boats, having been employed on convoy escort and other duties in the Atlantic, in all weathers, during the recent war.

The British ocean weather ships will carry civilian crews, and they will be administered by the Meteorological Office. Special accommodation will need to be fitted to house the crew of 12 officers, 20 petty officers and 22 ratings, to the modern standards laid down by the Ministry of Transport. A steel shelter will be erected on deck for the filling of radio-sonde balloons; special radio equipment, radar and motor lifeboats will need to be fitted. The work of conversion of these vessels will be carried out in Admiralty dockyards. It is probable that the ships will be based in the River Clyde area.

The photograph facing p. 32 shows H.M. corvette *Snowflake*, one of the vessels which has been allocated to the Meteorological Office. It will be appreciated that with the removal of her guns and the structural alterations necessary to convert her to an ocean weather ship her appearance will be considerably altered.

In addition to a normal complement of Deck and Engine Room officers and ratings, stewards and cooks, the ships will carry meteorologists and radio technicians. It is anticipated that each vessel will spend about 27 days at sea, followed by a spell of 15 days in port—which latter period is necessary for leave to be given to the ships' companies and for necessary repairs, storage and refuelling to be carried out. It is anticipated that the accommodation and food aboard the ships will be good and that generous leave will be given to the ships' companies.

When on station, in the Atlantic, the ships will, as far as possible, remain "hove to", more or less head on to the wind and sea. Navigation will need to be accurate to ensure remaining in the vicinity of their station, as far as possible, within reasonable limits in all weathers, but the ships will, of course, make way through the water and vary their position from time to time. Life aboard these small ships at sea will be relatively exacting, at times monotonous, at times exciting—but for the man who likes ships and the sea and the study of the weather, it will, in general, always be interesting. The work will undoubtedly be unusual, and apart from its importance for scientific and practical meteorological purposes, its potential value for the safety of human life is without question. Those who go down to the sea in ships . . .

SNOW COVER IN THE BRITISH ISLES

BY GORDON MANLEY, M.A., M.SC.

The experience of the three severe winters 1940-2 coupled with the war-time diffusion of much of our city population over the countryside directed attention to the frequency with which snow may be expected to cover the ground in various parts of Great Britain. Those of us who in pre-war years had to pursue their avocations in upland northern districts were well aware that this was a feature of the British climate which tended to be overlooked, a fact the more understandable when it is recalled how large a proportion of our population dwells in lowland towns of considerable size. In a paper by the present writer*, this aspect of British climatology was

* *Quart. J.R. met. Soc.*, London, 65, 1939, p. 2.

considered, using as a basis the figures published by the Meteorological Office since 1912. With the aid of some of the conclusions in this paper and making a more extensive survey of the data especially from lowland stations, it has become possible to illustrate the frequency of snow cover by means of a map. Few countries have as yet published maps of the distribution and frequency of snow cover; in western Europe indeed, the difficulties are considerable, as will be evident when the construction of the map under review is described. One of the most useful discussions of the duration of snow cover is that of Hebner for Germany.*

Snow cover has been observed and recorded in the British Isles at official stations since 1912; at first, rather few stations appear to have completed their records, and an examination of the figures also suggests that for a year or two some observers were not quite clear as to the criterion to be adopted. A day with "snow lying" is recorded, if at the 0900 observation the countryside surrounding the station, at the same level and typical of the station itself, is more than half covered with snow. Observations based on this criterion are now as a rule fairly consistent between adjacent stations, but in earlier years this was not always so. For example, one station in a Scottish mountain valley, although at a low level, recorded some remarkably high figures about the time of the last war quite out of keeping with any other station in the vicinity; after investigation the writer concluded that a temporary observer, probably carrying on under difficulties, had recorded "snow lying around the station" whenever snow covered the adjacent mountains 1,500 ft. or more above. After the war, however, the establishment of a number of permanent airfields (such as Cranwell, Lympne) and the renewal of more detailed observations at many climatological stations provided, from 1921 onward, a very consistent series of records, especially from country districts; and a further valuable series was forthcoming from many county agricultural stations after 1925. Country districts for obvious reasons are preferable to towns, as far as records of snow cover are concerned; more will be said about the effect of London in this respect.

It must not be forgotten that observations of snow cover, even when the criterion is carefully laid down from headquarters and applies to a single fixed hour, are not always easy. In Cambridgeshire for example, the winters of 1940 and 1942 provided a considerable number of days when a thin powdering of snow covered considerably more than half of a large grass playing field adjacent to the writer's house. But ploughland in the neighbourhood at the same time did not give an impression of prevailing snow cover at all, except at times when one approached a field in which the furrows ran east and west. As nearly three-quarters of Cambridgeshire is ploughland, observers locally are often liable to differ in their opinion whether the countryside is or is not thinly covered. In more hilly districts the observer's opinion may well be swayed in favour of snow cover in places where most of the slopes in view have a northerly aspect and remain largely covered with snow when southerly slopes, or even ground at the level of the observer would be virtually free from snow. There are also a few exposed stations at which snow, on the majority of occasions on which it falls, is liable to drift considerably; around such stations there may be considerable drifts in the

* Die Dauer der Schneedecke in Deutschland. Stuttgart, 1928.

roads and in the lee of walls, yet the ground is often sufficiently clear at the observing hour for the observer to record "no snow cover". But when a large number of stations are compared, discrepancies arising from the various causes are to some extent smoothed out; for the map under review, upwards of 150 stations were used. It was, however, throughout necessary to bear in mind the characteristics of the station and the probable reactions of the observers. For example, in considering the frequency of snow cover on the southern Pennines more weight was attached to the record from Oakes, near Huddersfield, than to that from Buxton, inasmuch as the Buxton station is well in the middle of the town and the earlier figures from it did not always appear to be consistent with other upland records; they tended to be on the low side, and there is no reason to suppose that Buxton lies in an exceptional "snow shadow".

Some notable difficulties arose from a familiar cause; the thoroughly irregular distribution of stations. Decisions with regard to the frequency of snow cover in north Wales for example rest largely on the observations from Rhayader and Welshpool, with a very brief and imperfect record from Pen-y-Gwryd in Snowdonia. To this may be added the assumption based originally on the writer's observation of the frequent diminution westward in the amount of snow cover, with a corresponding rise in the snow line in a month such as March; this is a well known feature of most of our British hill ranges. That diminution in amount is accompanied by diminution in the number of days of snow cover is borne out by observations from such Pennine stations as Oakes and Darwen in northern England, or West Linton and Eskdalemuir in southern Scotland, and Craibstone, Logie Coldstone, Glencarron and Achnasheen farther north. Even in the English Midlands, one of the largest gaps covers almost the whole of the uplands (Mendips, Cotswolds, Northamptonshire, Leicestershire); throughout this area, eight years' record from Cirencester (443 ft.) and eight from Leafield (612 ft.) with a patchy record from Rugby (390 ft.) afforded very scanty material from which to deduce how frequently a snow cover may be expected on the large area above 700 ft. Since these data were compiled stations at Little Rissington, Whipsnade, and also Vyrnwy in north Wales have begun recording; so far, their results agree well with the estimates.

The frequency of snow cover is a climatological element subject not only to great variations from place to place, but also from year to year. The necessary compilation of available data was made in the early part of the war, and covered the years 1912-38. It was soon observed that over most of the country there were two exceptional years, 1917 and 1919, with a third (1937) rather less conspicuous in the statistics. By way of illustration, West Linton, with an average of 39.2 days yearly, recorded 88, 74 and 69 mornings with snow cover in these three outstanding years (also 70 in 1942), Eskdalemuir (average 24.7 days) recorded 90, 41 and 43 (68 in 1942), Cambridge (average of 7.7 days) 32, 28, 15 (29 in 1942) and Darwen in Lancashire (average of 12 days) 40, 34 and 27 respectively (1942, no record). In many places 1916 was also rather snowy; hence it will readily be seen that the average for any given station would be likely to be considerably affected by the inclusion or omission of the years previous to 1920.

It may now be asked, what would the effect be if the data for the three severe winters of 1940-2 and the cold January of 1945 were incorporated

in these averages. So far as snow cover is concerned the winters of 1941 and 1942 were comparable in many places with 1917 and 1919, and again, if these two outstanding years are included the effect will in general be to raise the averages for the whole period by a figure commonly of the order of 10 per cent. But it is not to be forgotten that the snow-free winter of 1943-4 goes some way towards redressing the balance. For the present it would seem reasonable to retain these averages for snow cover, 1912-38, which compare very closely with those for 1920-46. We can associate these averages with the published 30-year averages of temperature for 1906-35 or the unpublished series for 1911-40, and make further adjustments at the end of the present decade. By 1950 there will not only be a better network of stations, for example on the high Cotswolds and in north Wales, but more evidence will be forthcoming with regard to a possible incipient trend in the direction of severer winters corresponding with those prevailing between 1870-97. It is also worthy of recall that the late winter and spring months have tended in recent years to be relatively mild, and that in 1940-1, and again in 1941-2, there was little snow before January. Comparative figures are appended, in Table I, for six stations with longer records, which will serve to show the effect of the four cold Januaries since 1939. It will be seen that the annual totals at the lowland stations are affected; Braemar shows little difference.

TABLE I—SNOW COVER : AVERAGE MONTHLY FREQUENCY

		Jan.	Feb.	Mar.	Apr.	May	Sept.	Oct.	Nov.	Dec.	Year	Range of Variation
Braemar, 1,120 ft.	1913-38	16.3	13.0	11.8	4.8	0.7	0.1	2.0	5.5	13.0	67.2	32 to
	1913-45	17.2	13.9	11.7	4.3	0.7	0.1	1.7	5.3	11.9	66.8	142
West Linton, 770 ft.	1912-38	9.5	8.7	7.6	1.8	0.1	—	0.8	3.6	7.2	39.3	13 to
	1912-45	11.0	9.0	6.9	1.5	0.1	—	0.6	3.0	6.5	38.6	88
Ushaw, 594 ft.	1912-38	4.9	4.6	4.7	0.8	0.1	—	0.1	1.4	4.0	20.6	3 to
	1912-45	6.6	5.2	4.2	0.7	0.2	—	0.2	1.3	3.6	21.8	69
Cambridge, 41 ft.	1912-38	2.3	2.1	1.1	0.2	0	—	0	0.3	1.7	7.7	0 to
	1912-45	3.6	2.6	1.1	0.2	0	—	0	0.2	1.5	9.2	32
Southport, 30 ft.	1912-38	1.6	1.0	0.8	0.1	0	—	0.1	0.7	0.6	4.9	0 to
	1912-45	2.5	1.4	0.8	0.1	0	—	0.1	0.5	0.6	6.0	28
Kew, 18 ft.	1913-38	1.0	0.9	0.5	0.1	0	—	0	0.2	0.8	3.5	0 to
	1913-45	2.1	1.0	0.4	0.1	0	—	0	0.2	0.7	4.4	20

Features of the map.—Considering the coastal lowlands first : practically everywhere in a narrow strip round the coast from Norfolk to the Solway and north to the west of Scotland as far as Wester Ross, less than five mornings yearly with snow cover are to be expected. The strip broadens to include the whole of the lowlands of Devon and Cornwall below about 500 ft. (cf. Tavistock, 4.4 at 457 ft. and Redruth, 3.1 at 397 ft.). The neighbourhood of the Severn estuary (Cardiff, about 4) and a considerable patch of Hampshire are also included (South Farnborough, about 5) ; this appears to

result from the fact that both areas lie in a slight " snow shadow " with regard to winds from between N. and E. Immediately adjacent to the sea the south and west coasts of England give about four days in Kent, two along the Sussex coast and round Southampton Water, between one and two in south Devon, less than one in Cornwall and west Pembrokeshire, nearly two at Holyhead, less than four at Douglas and five at Southport. Various places on the western Scottish islands and coasts give from two to five days, rising to six further inland at Greenock and Rothesay.

All the evidence goes to show that the inner London area records less than five days ; the suburban stations generally give just under five, South Kensington about three, but Hampstead (450 ft.) records an average of 12·9 days.

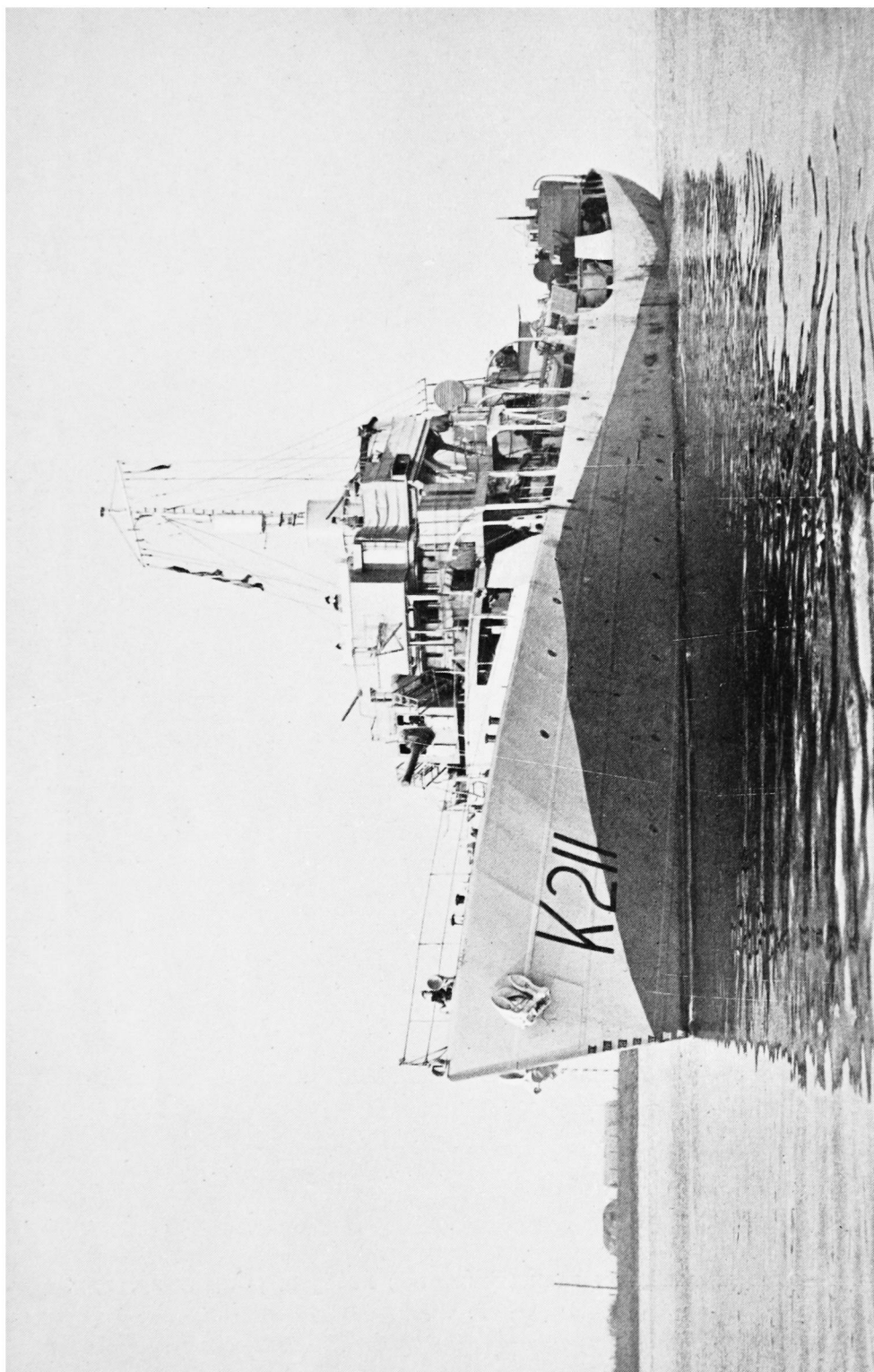
The strip with less than five days yearly becomes very narrow along the east coast of Norfolk (Yarmouth nearly 5, Bungay above 7, Copdock above 8). Northward, Cromer has nearly 6 days, Skegness 6·8, Hull 7·1, but Spurn Head only 2·5, Scarborough 5·4, Tynemouth over 7. The average is generally from 6 to 8 on the eastern Scottish coast south of Angus, rising to 10 in Edinburgh and 12·6 at Aberdeen ; it is generally about 10 very close to the Moray Firth, at Wick and in the lower Orkneys and Shetlands. In all this region however the rise in frequency with altitude is very rapid ; near Aberdeen, Craibstone (325 ft.) records upwards of 25 days, and further inland Logie Coldstone (608 ft.) about 39 days. This very rapid rise in frequency of snow cover with altitude on our north-eastern coasts has already been discussed at some length in the paper cited above. It also applies very markedly near the coast of east Kent,* and probably the " 5 " and " 10 " isopleths as drawn on this map should be carried nearer the Kentish coast in spite of the low records from Margate and Dover on the coast itself.

The greater part of the southern English lowlands, e.g. in the Thames and Severn valleys, the Fenland, and also a large area in Shropshire, Cheshire and south Lancashire and smaller patches near the Humber and Carlisle experience from seven to ten mornings yearly with snow cover (Oxford 7·7, Cambridge 7·7, York about 11, Shrewsbury about 8, Welshpool 9·2, Leyland near Preston 8·5). To the south-west Marlborough even at 424 ft. averages only about 8 ; Cullompton (Devon) 3·8 illustrates the decrease towards Exeter.

With altitude and distance inland the increase is marked, especially towards the east coast. The higher North Downs generally exceed 10, with parts of the South Downs (Tunbridge Wells, 355 ft., nearly 8). In East Anglia, Norwich has over 12 days, Halstead (inland Essex) nearly 12 ; further inland, small areas on the highest of the Chilterns probably record upwards of 20 days. The whole of the higher ground of the Midlands and the Trent valley may expect from 10 to 15 at least (Birmingham, 535 ft., about 10 ; Mayfield near Ashbourne, 374 ft., about 16 ; Cranwell, 230 ft., over 14). Part of the lowland of Northumberland, Durham and north Yorkshire, with the Midland valley of Scotland falls into the 10-15 region (Catterick 13·5 ; Glasgow district, 10 at lower levels).

Northward and eastward, the rise on the flanks of the Pennines is marked, and if space and other circumstances had allowed the map could undoubtedly

* See J. H. Dyson ; *Quart. J.R. met. Soc., London*, 68, 1942, p. 261.



H.M. CORVETTE *Snowflake*
(see p. 28)



FIG. 1—RIME AT ALLERTON PARK (YORKSHIRE) AT 1520, JANUARY 25, 1945
(see p. 46)



FIG. 1—NUMBER OF MORNINGS WITH SNOW LYING, ANNUAL AVERAGE, 1912-38

have been improved by the inclusion of the "15" isopleth. There is probably a considerable area in high Leicestershire as well as most of Nottinghamshire with 15-20 days; Mansfield nearly 19 at 357 ft. and small areas may just exceed 20. Much of industrial Yorkshire and Durham also falls into this category (Huddersfield 17, Meltham 16, Durham 17), but on the lee side of the Pennines the average frequencies at similar levels are lower

(Giggleswick about 16, Stonyhurst about 9, Darwen 12). All the evidence indicates that the shores of Morecambe Bay are relatively free from snow cover, no doubt on account of the fact that the region frequently lies in a "snow shadow" so that the quantity in any given fall is commonly a good deal smaller than further east; further there are fewer snowfalls (cf. the article by the present writer in the *Meteorological Magazine*, London, 75, 1940, p. 41).

Snow cover at higher levels.—One of the chief defects of British climatology arises from the shortage of high-level records; there are very few stations at levels above 1,000 ft. Deductions with regard to the frequency of snow cover on high ground must largely be based on the observed rate of increase in places where stations at different altitudes lie close together (cf. York 11 days, Harrogate (478 ft.) 21, Cally 5, Dumfries 11, Eskdalemuir 25). It has been already shown in the paper cited above that these increases can in large measure be related to the mean temperature in such a way as to make it possible to calculate the probable frequency of snow cover at higher levels.

On this basis, the greater part of the central and eastern Pennines above 1,000 ft. may expect over 30 days with snow lying; this becomes 50 or more in several upland areas, above about 1,600 ft., notably round the Peak and in several larger upland areas further north; the largest lies on the Durham-Cumberland-Westmorland border. The Upper Teesdale record, kept by the writer at 1,840 ft. indicates an average frequency of snow cover of about 80 days. The east Yorkshire uplands, although generally lower, have also a high expectation of snow cover; from 20–30 days on the higher Wolds, and upwards of 30 on all the higher moors towards Cleveland (Castleton, 450 ft., about 25). Elsewhere on a small-scale map it is impossible to show the detail on all summits; but it will be observed that a strip "between 30–50 days" almost connects the Pennines and the Lake District across Shap Fell. Not far away in Northumberland, Bellingham (849 ft.) averages about 31 days.

Considerable areas in the Southern Uplands of Scotland (Leadhills, 1,310 ft., 61 days on a short record) and a very large area in the central Highlands have over 50 days (Balmoral 60·2, Braemar 67·2, Dalwhinnie probably over 60). In this district a sizeable region, notably in the eastern Highlands, is shown as "more than 100 days". Small areas further north and south, generally too small to show on a map of this scale, may also exceed 100 days, for example on the highest summits of the Southern Uplands, the Lake District, Crossfell and north Wales. On the summit of Ben Nevis (4,406 ft.) the number of days with snow cover is of the order of 230 days.

At high levels however, it is not safe to say that the frequency of snow cover increases with a close relationship to the fall of mean temperature. Drifting removes much of the snow cover from the summits, and in the winter of 1940 for example it was observed that the upper slopes of Helvellyn above 2,000 ft. were largely bare while the valleys were still heavily and continuously covered. Attempts have been made to estimate the duration of large snow drifts at high levels, i.e. above 2,000 ft., and it would appear that in any given year "large drifts" are likely to survive for between one third and one half as long again as "snow cover". This is important especially with regard to upland roads; so many of these are badly sited and may remain blocked by drifts even when the surrounding countryside is almost entirely clear.

Little has been said hitherto with regard to snow cover in Wales. As elsewhere, upland stations are few and deductions rest to a considerable degree on the data from Rhayader (757 ft., about 16 days), Cantref (1,080 ft., probably 16 days) and the Herefordshire station of Bromyard (393 ft., 9 days) with occasional brief records from elsewhere, e.g. an older record from Wistanstow in Shropshire. The evidence goes to show that much of the Welsh upland, although relatively high is considerably freer from snow than the Pennines, especially towards the south-west. The Brecon Beacons too appear to afford an interesting example of "snow shadow" with regard to the valleys lying to the south and west. Towards Pembroke the diminution is reminiscent of Cornwall (Haverfordwest 5.0, Swansea 2.4, Aberystwyth 1.0, St. Ann's Head 0.5 days).

Dartmoor presents an interesting problem; in occasional years a Channel snowstorm, as one may call it, resulting from a winter secondary passing up-channel, gives, for orographic reasons, a very heavy and lasting accumulation on this upland. But many years pass without any exceptional fall of this kind, and the reputation of Dartmoor for snowfalls seems to be somewhat exaggerated if the average experience of the period 1912-38 is any guide. Although Princetown is the highest of the official stations in Great Britain (1,359 ft.) the average yearly number of mornings with snow cover is only about 17. It is probable that there is a small area towards the northern end of the moor with about 30 days. This average of 17 mornings yearly still holds for Princetown when the years 1939-45 are included.

In recent years the Association for the Study of Snow and Ice (now the British Glaciological Society) has begun to collect more precise data with regard to the frequency and duration of snow cover at high altitudes, but this work had to be discontinued during the war. A note on some of the results will be found in the *Quarterly Journal of the Royal Meteorological Society* for January 1941. This work has now been revived and contributions from upland observers will be very welcome.

Ireland.—Here again there are only too few stations; it is however evident that a very large part of the lowlands can expect less than five days yearly with snow cover (Birr Castle about 4 days, Armagh 7.3, Newtonforbes about 7, Markree upwards of 4, Dublin (Phoenix Park) less than 4). One station only records from above 500 ft. (Seskin, 535 ft., in south-east Ireland, with 5.2 days). The southern and south-western coasts resemble those of Cornwall in having everywhere less than 1 day; and it would appear that only small areas on the highest of the mountain ranges are likely to carry snow for upwards of 30 days. Even the areas with more than 10 days are restricted to small patches above 400 ft. in the north-east, and perhaps 1,000 ft. further to the south.

Conclusion.—It must be remembered that the accompanying map represents the distribution of a climatic element for which the data are as yet imperfect. It would scarcely be wise at this stage to endeavour to make a detailed map; and the mapping of the monthly frequencies of snow cover is also difficult as yet, indeed perhaps inadvisable until a longer term of years is available. One of the most noteworthy features, however, at the more northern high-level stations is the frequency of snow cover in March and April by comparison with the south; it will be noted that in the north the chance of snow cover in March is nearly as great as in January (1912-38) although the inclusion of 1939-45 somewhat restores the balance.

It is also not impossible that as our knowledge grows more light may be thrown upon the relationship between snow cover and soil temperature. For example, the rather low frequency of snow cover in the Fens compared with the same level in the inner parts of Essex and Suffolk (Cambridge 7·7, Halstead 11·6), may possibly owe something to the soil temperature as well as to a decreased supply of snow. There is much room for further work in regard to this hitherto neglected element of the British climate.

Some readers may also question the relationship between "mornings with snow lying at 0900" and "days of snow cover". There is reason to believe that the number of mornings with snow lying and the number of whole days with snow cover are approximately equal whenever the mean temperature of the month in question is below 38° F.; but this is not yet conclusive. Nevertheless, for the majority of our uplands the accompanying map can be regarded as a reasonably close representation of the duration of snow cover in an average year, apart from occasional scattered drifts.

The range of variation between extreme years is large; some typical examples are given for six stations in the table above. Taking the stations with long records into account it would appear that, at inland places averaging 10 days yearly, the probable range of variation is from 0 to between 30 and 40 days. Stations at which the average is 20 may record up to 70 days with snow cover in an extreme year; as a whole we may say that in an occasional year snow cover will be experienced up to between three and four times the average expectations. At the higher-level eastern Scottish stations the range of variation appears to be less, from rather under half to just over double the normal; at western Scottish stations the variability is greater. Elsewhere, mild coastal stations with an average between three and five days may occasionally record from 15 to 20. In the other direction it may be said of the majority of stations with averages of less than 12 days that an occasional year will occur without snow cover being recorded.

THE NUMERICAL BASIS OF CLIMATE

BY C. E. P. BROOKS, D.SC.

Part II.—Frequency Curves

In Part I two examples were given of the frequency distribution of temperatures, and Fig. 1 showed how the numbers of observations in each two-degree step form a symmetrical curve with a peak in the centre. The progression is not quite regular, but we can reasonably suppose that this is due to the limited number of observations, and that if instead of only 300 days we had many thousands, the small irregularities would almost completely disappear. The disadvantage of a short series can be largely overcome in many cases by constructing a theoretical "frequency curve" to represent the distribution which would probably be given by such a large number of observations.

The theory of frequency curves was first developed in the study of errors of observation. For example, consider the barometric pressure in a room at some particular instant of time, and suppose that in the room there is a large number of barometers with a different observer for each instrument, reading it to a thousandth of an inch. All the readings, corrected for temperature,

ought to be the same, but in practice they would be found to show small discrepancies. These might be due to small differences in the barometers or attached thermometers, different errors of parallax, small differences of time in reading (if pressure is changing) and many other causes—the list is endless. Over the whole series of observations positive and negative errors will tend to cancel out, and the most probable value of pressure in the room is the mean of all the readings. But with one observer negative errors may predominate and the actual reading will be lower than the mean, with a second, positive errors may predominate, while with a third, positive and negative errors will be equal and the reading will be correct. In most readings positive and negative errors will nearly, but not quite, cancel out, and readings near the mean will be more numerous than those departing widely from it.

In the case of the barometer readings the errors are of human origin, but that is not a necessary feature. Thus we can regard the 1300 temperature on any one April day as a shot by nature at getting the normal 1300 temperature in April, disturbed by a whole series of small “accidents”—wind, rain, sun, etc.—each of which is as likely to contribute to a high as to a low temperature. Thus the theory of errors can be applied equally well to climatological observations. Let us see how this theory can be used to calculate a frequency curve.

Suppose that we toss up two pennies. There are four possible results, all equally likely—two heads ; head, tail ; tail, head ; two tails. In 400 trials we should expect to come near the following result (though it is unlikely that it would be realised exactly) :—

Number of heads	..	2	1	0
Frequency	..	100	200	100

It is more convenient to describe the distribution in terms of the “probability” of any single event as a fraction of unity, an event which is certain to occur (for example that the two pennies will come down head or tail and not on edge) having a probability of 1·0. The probabilities of 2, 1 and 0 heads are therefore respectively $\frac{1}{4}$, $\frac{1}{2}$, $\frac{1}{4}$. If we tossed three pennies we might have 3, 2, 1 or 0 heads and a little calculation will show that the probabilities of these results are respectively (in eighths), 1, 3, 3, 1. Anyone familiar with elementary algebra will recognise at once that the numbers 1, 3, 3, 1 are the coefficients of the terms in the expansion of the binominal $(a + b)^3$. To reduce them to fractional probabilities, we consider that since the probability of a head or of a tail is the same, $a = b = \frac{1}{2}$, and the probabilities for any one throw are given by the actual terms of the series $(\frac{1}{2} + \frac{1}{2})^3$, namely

$$(\frac{1}{2})^3, 3 (\frac{1}{2})^2 (\frac{1}{2}), 3 (\frac{1}{2}) (\frac{1}{2})^2, (\frac{1}{2})^3.$$

If we tossed n pennies at once, the probabilities of n , $(n - 1)$, . . . 0 heads would be given by the expansion of $(\frac{1}{2} + \frac{1}{2})^n$.

In nature the sources of error are by hypothesis unlimited, and in an element such as temperature which is as likely to be above as below the mean, n becomes infinite. The number of points in the expansion of $(a + b)^n$ also becomes infinite ; in other words, they trace out a continuous curve, which is symmetrical about the mean value. This is known as the “normal frequency curve”, and its shape depends solely on the value of σ , the standard deviation of the observations. As explained in Part I, the standard

deviation is the square root of the mean of the squares of the differences of the individual observations from their average. Hence, if we know the mean and standard deviation of a limited series of observations, we can determine the distribution which would most probably be given by a very much larger number.

TABLE III—NORMAL FREQUENCY DISTRIBUTION

Probability (P) that a positive or negative value of x/σ will be equalled or exceeded (values = $P \times 1,000$).

x/σ	.00	.01	.02	.03	.04	.05	.06	.07	.08	.09
0.0	500	496	492	488	484	480	476	472	468	464
0.1	460	456	452	448	444	440	436	433	429	425
0.2	421	417	413	409	405	401	397	394	390	386
0.3	382	378	375	371	367	363	359	356	352	348
0.4	345	341	337	334	330	326	323	319	316	312
0.5	309	305	301	298	295	291	288	284	281	278
0.6	274	271	268	264	261	258	255	251	248	245
0.7	242	239	236	233	230	227	224	221	218	215
0.8	212	209	206	203	201	198	195	192	189	187
0.9	184	181	179	176	174	171	169	166	163	161
1.0	159	156	154	151	149	147	145	142	140	138
1.1	136	133	131	129	127	125	123	121	119	117
1.2	115	113	111	109	107	106	104	102	100	99
1.3	97	95	93	92	90	89	87	85	84	82
1.4	81	79	78	76	75	73	72	71	69	68
1.5	67	65	64	63	62	61	59	58	57	56
1.6	55	54	53	52	51	50	49	48	47	46
1.7	45	44	43	42	41	40	39	38	37	37
1.8	36	35	34	34	33	32	31	31	30	29
1.9	29	28	27	27	26	26	25	24	24	23
	.0	.1	.2	.3	.4	.5	.6	.7	.8	.9
2	23	18	14	11	8	6	4.7	3.5	2.6	1.9
3	1.3	1.0	0.69	0.48	0.34	0.23	0.16	0.11	0.07	0.05
4	0.032	0.021	0.013	0.009	0.0054	0.0034	0.0021	0.0013	0.0008	0.0005

A , the proportion of the total area to the left of the ordinate corresponding to x/σ , is given by $A = 1 - P$ for positive values of x/σ and by $A = P$ for negative values of x/σ .

In practice the distribution is usually given in the form of the fraction of the area (marked out by the curve and the base line of zero frequency) which lies to the left or right of the vertical representing any given fraction of the standard deviation. In case any readers would like to try the rather fascinating game of fitting a normal frequency curve, a table is given here (Table III). As an example, we will apply it to the data for Scilly given in Part I. We have :

$$\text{Mean temperature} = 51.38^\circ \text{ F.}, \sigma = 3.03^\circ \text{ F.}$$

The process is quite simple. The steps of temperature in Table I are each 2° F., so that the steps of $x/\sigma = 2/3 \cdot 03 = 0.66$. The values 49.95 and 51.95 on either side of the mean of 51.38 differ from the latter by -1.43 and $+0.57$ respectively, giving values of $x/\sigma = -0.47$ and $+0.17$. From these we proceed upwards and downwards by adding 0.66 successively. The calculation for a few steps is shown in Table IV.

TABLE IV—CALCULATION OF A NORMAL FREQUENCY CURVE

Temperature limits	x/σ	Probability per mille (Table III)	Difference	Difference $\times 0.3$
° F.				
45.95	-1.79	37		
			92	28
47.95	-1.13	129		
			190	57
49.95	-0.47	319		
			181	248
Mean (51.38)		(500)	67	
				74
51.95	+0.17	433		
			230	69
53.95	+0.83	203		

The third column, probability per mille, is read off against the value of x/σ in Table III, and gives us the total frequency of values below 51.38, 49.95, 47.95, etc. or above 51.38, 51.95, 53.95, etc. The differences between these probabilities give the probability per mille of a reading in the corresponding temperature step. Thus since we expect 319 observations per mille below 49.95° F. and 129 per mille below 47.95° F., the difference, 190, is the expectation for the range 47.95 to 49.95. To reduce this to a total of 300 observations, we multiply by 300/1000 or 0.3. For the central step, 49.95 – 51.95, we add together the expectations for the ranges 49.95 – 51.38 and 51.38 – 51.95. The calculated values are shown by the smooth curve in Fig. 3, in which the observed values are indicated by crosses. It will be seen that the smooth curve threads its way evenly among the crosses, indicating that the normal frequency curve is a good “fit” for the observations.

The normal curve is only one of a great number of possible frequency curves, but it is the most typical of those met with in climatology. Many distributions are generally similar, but are not quite symmetrical, falling off from the peak more steeply on one side than the other ; these are known as “skew” curves. Annual, and to a still greater extent, monthly rainfall totals for example are generally steeper on the left, so that the highest values are further above the mean than the lowest values are below the mean. This is to be expected, for rainfall has a lower limit at zero, but no upper limit ; it may (and monthly totals often do) exceed the mean by more than the mean value. Other curves are quite different ; the frequency of daily rainfall gives a “J” curve, high on the left and decreasing continuously to the right, and the frequency of individual cloud amounts in western Europe gives a “U” curve, high at both ends.

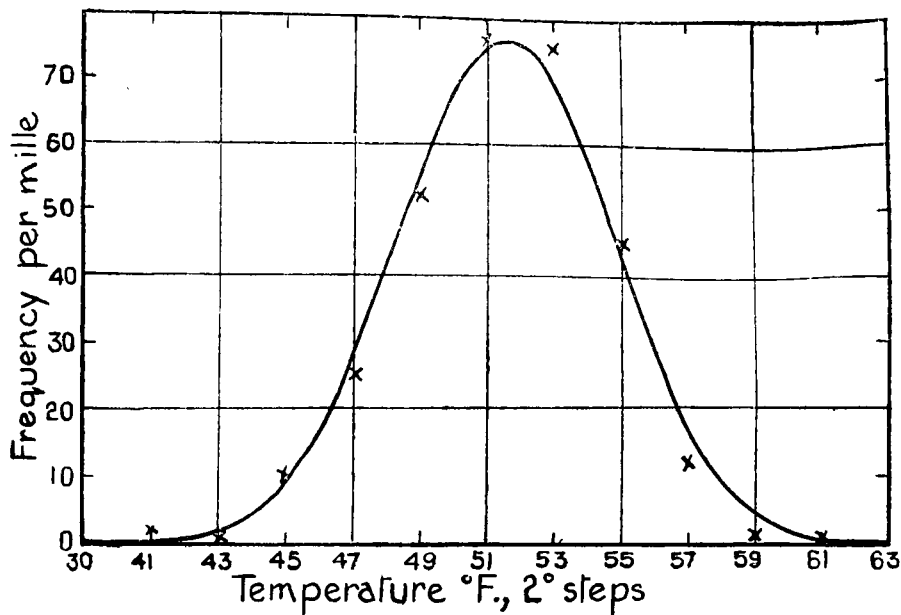


FIG. 3—OBSERVED AND COMPUTED FREQUENCIES OF TEMPERATURE AT SCILLY, APRIL, 1300, 1928-37

Fig. 4 is a histogram of the annual rainfall at Glenquoich, Scotland, 1869-1943. The horizontal lines show the observed frequencies. The broken line shows the result of fitting a normal frequency curve, and it can be seen that while this represents the general run of the histogram it shows appreciable discrepancies, especially in the extreme values, while the "mode" occurs at 111 in. (which is of course the mean annual rainfall) instead of at 104 in. In such a case, where the departures from the normal curve are not too great, the latter can be "adjusted" by taking account of the

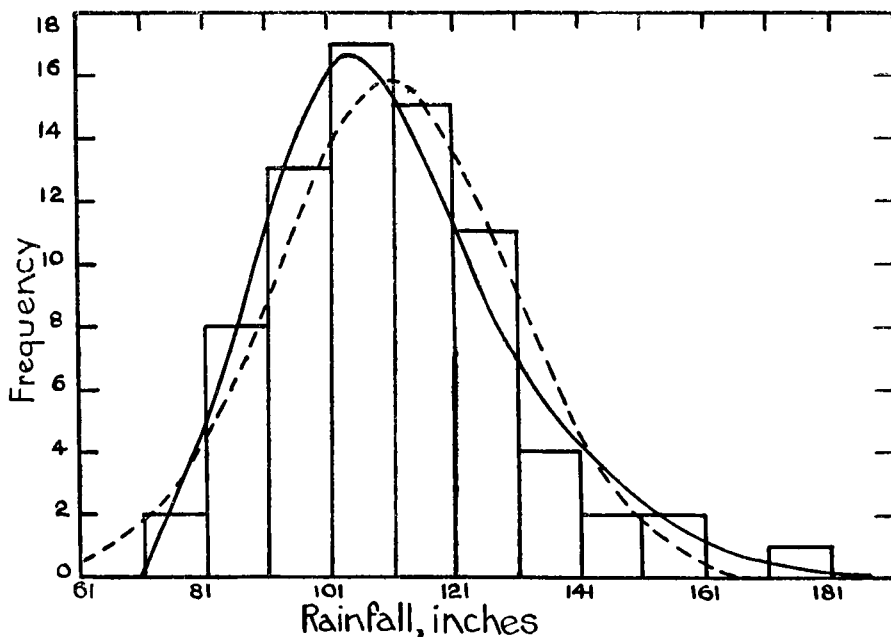


FIG. 4—FREQUENCY DISTRIBUTION, ANNUAL RAINFALL, GLENQUOICH

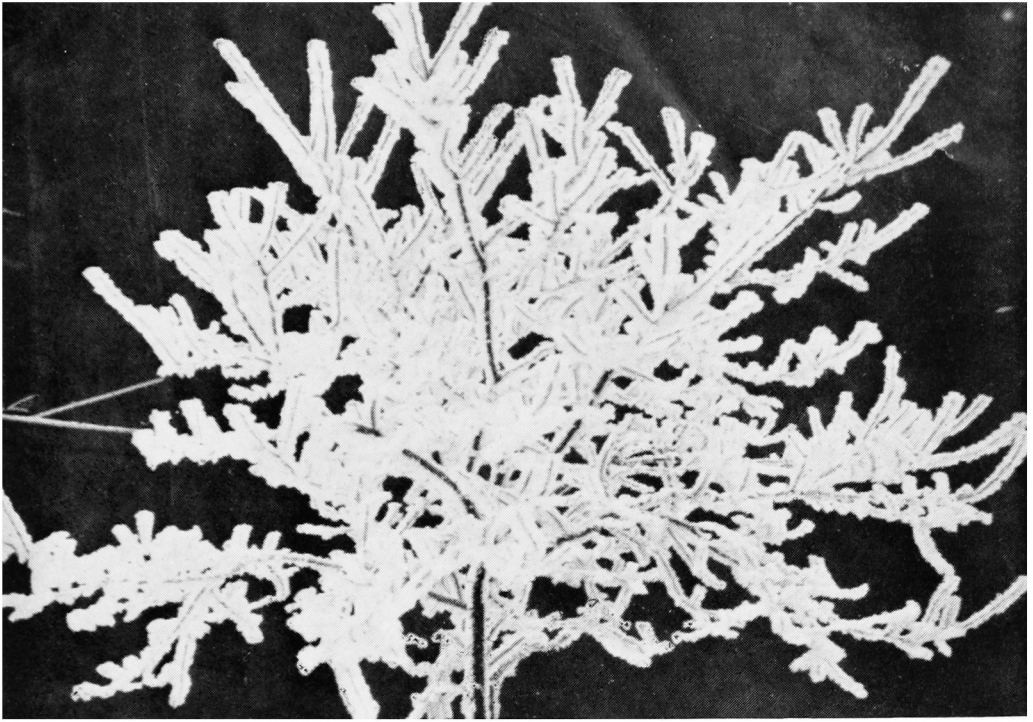


FIG. 2—RIME AT LINTON-ON-OUSE (YORKSHIRE), JANUARY 24, 1945
(see p. 46)



FIG. 3—RIME AT DOWNHAM MARKET (NORFOLK), DECEMBER 27, 1944
(see p. 46)



FIG. 4—RIME AT KILLADEAS (NORTHERN IRELAND), FEBRUARY 1, 1945
(see p. 46)



FIG. 5—RIME AT KILLADEAS (NORTHERN IRELAND), FEBRUARY 1, 1945
(see p. 46)

cubes as well as the squares of the departures from average. Since the squares are always positive, they must give a symmetrical curve, but the cubes have the same sign as the original departures. Hence the sum of the cubes is a measure of the skewness, and its sign, plus or minus, indicates whether the frequency is extended upwards or downwards. A description of the process of fitting an adjusted frequency curve would be beyond the scope of this article, but the result is shown by the full line of Fig. 4. This is a very good fit.

Fig. 5 shows the mean annual frequency of days exceeding various amounts of rain at Kilmarnock. Thus in an average year there are 211 days of 0.01 in. or more, 167 days of 0.04 in. or more, and so on, up to 2 days of 1 in. or more. The values are marked by crosses and a smooth curve has been drawn through them by eye. With curves of this shape it is often worth while to plot them in a different way, and the small circles show the logarithm of the frequency plotted against the amounts of rainfall. The points now lie very clearly

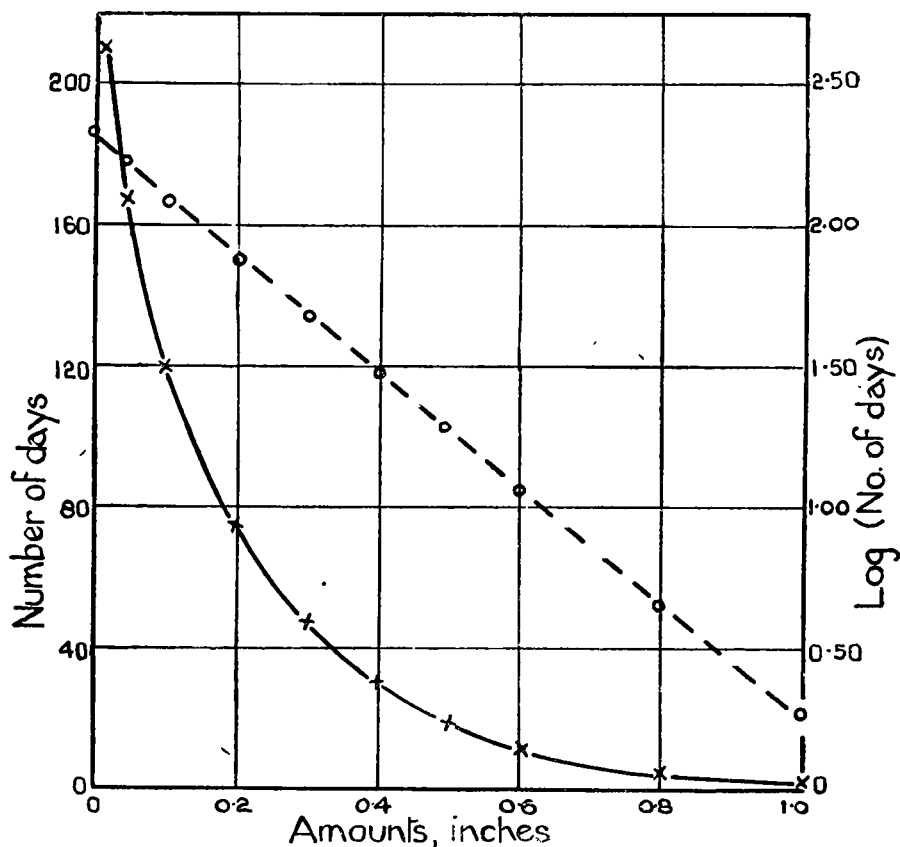


FIG. 5—NUMBER OF DAYS EXCEEDING VARIOUS AMOUNTS OF RAIN AT KILMARNOCK

along a straight line. If we put r for the amount of rainfall and f for the frequency with which it is exceeded, the equation of the straight line is very nearly

$$\log f = -2r + 2.3.$$

This enables the probable number of days exceeding any other limit to be calculated. For example, if $r = 1.5$ in., $\log f = -0.7 = \bar{1}.3$, and the expected frequency is 0.2 or once in five years. Actually there were 7 such falls in 29 years.

Fitting frequency curves to the less simple types of distributions, especially those which are cut off sharply at one or both ends, such as individual cloud amounts or Beaufort wind forces, is difficult and laborious, and is probably rarely worth while for meteorological data. A classification of frequency curves and descriptions of how to fit them are given by W. P. Elderton in "Frequency Curves and Correlation" (3rd edition, Cambridge, 1938).

(To be continued)

METEOROLOGICAL OFFICE DISCUSSIONS

Monday Evening Discussions of foreign papers of special interest were started as a feature of Meteorological Office activities by Sir Napier Shaw as long ago as 1905 and always proved popular. The opportunity of refreshing old acquaintances in an informal atmosphere must account for much, but it is also pleasant, as well as useful, for the staff, many of whom are much pre-occupied with the business of providing and administering meteorological services, to meet on the plane of scientific progress.

These meetings, which occurred on alternate Monday evenings between October and March, were held with little interruption until March, 1939. The outbreak of war prevented them from being resumed in October, 1939. It was with considerable pleasure therefore that it was learnt some time ago that the Director, Sir Nelson Johnson, could now see his way to re-opening the series. His selection for the inaugural meeting on February 10 was the paper by V. J. Oliver and M. B. Oliver "Forecasting the weather with the aid of upper air data"*, with an invitation to Dr. R. C. Sutcliffe to open the discussion.

The meeting was attended by some 120 of the staff, many of whom had come up from their stations in the country for the occasion. After the informal atmosphere had been created over a welcome cup of tea the Director introduced the session with remarks on the purpose of the meetings including a tribute to the late Sir Napier Shaw, the founder of the Discussions.

With the aid of illustrations from the paper, projected by the epidiascope, Dr. Sutcliffe then gave a fairly complete account of the paper, which in his opinion was ideal for the basis of a discussion containing as it did so many practical propositions for the consideration of the forecaster, propositions which were related mainly with the dynamical behaviour of the atmosphere. The paper covered so much ground that the authors had been compelled to reduce the theoretical arguments to almost skeleton form, and Dr. Sutcliffe suggested that this was scientifically regrettable, as incomplete theorising, of the facile descriptive variety, was unconvincing to the critical reader. Nevertheless he was persuaded that many of the rules given were a fair statement of what was actually observed to occur, and that the arguments based on Rossby's vorticity considerations and on shear of wind with height could not lightly be dismissed even if they were open to criticism. Amongst the many comments made in the course of his account mention might be made of his warning that although frontal characteristics were modified by the overrunning or the lagging behind of the upper wind, one could not infer upsliding or downsliding—essentially dynamical processes—with a simple

* Published by the Institute of Meteorology, Chicago University, 1944.

kinematical picture of air descending or ascending above a wedge of cold air regarded as acting like a solid wedge ; and, another point, that the notion of pressure changes by advection of warm or cold air was something which could be used to account for almost anything, that the authors had used warm air advection to account for rising pressure at 10,000 ft. and for falling pressure at the surface according to convenience ; they could not have it both ways, at least not to carry conviction. But Dr. Sutcliffe was a convinced disbeliever in the implications of advection except as defining the difference in pressure between one level and another ; only dynamical consideration would determine at what level the changes took place.

The Deputy Director, Mr. E. Gold, then made a few pertinent remarks and threw the meeting open to discussion and it was stimulating to see how many of the younger members of the scientific staff were ready to make considered contributions. Mr. Kirk interested everyone with a reference to his meeting Mr. Oliver and Dr. J. Bjerknes in Italy and to a discussion there of these same problems. Mr. Miles, now on Prof. Brunt's staff at the Imperial College, brought up the question of Rossby's trajectories with north-easterly winds in connexion with cyclonic development which he said seemed to work well on some occasions but not on others. Mr. Matthewman, from the upper-air section at Dunstable, provided some very rapid and neat quantitative inferences from the fundamental equation relating vorticity changes with divergence, and showed that appreciable cyclonic curvature might be present in a wind of southerly origin without any convergence having occurred. He was also sceptical about the ignoring of lateral shear as compared with streamline curvature in the vorticity determination. He noted that in solid rotation the shear and curvature terms are of equal magnitude ; and that a small shear of 2.5 m.p.h. in 100 miles, difficult to observe in practice, might be equivalent, in a practical example, to the change in apparent vorticity due to movement across five degrees in middle latitudes.

Mr. C. K. M. Douglas, head of the Central Forecasting Branch of the Office, was very alive to the importance of the dynamical approach but stressed the absence of any agreed principles or accepted technique which could at present be applied to a routine service as distinct from a research organization.

After other contributions Dr. Sutcliffe replied with the statement that in his opinion one weakness was that vorticity considerations alone ignored the necessity for ensuring that the field of pressure was suitably modified to fit the changing field of motion. Other writers, by contrast, studied the changes in the pressure pattern and tended to ignore the processes required to bring the circulation into quasi-geostrophic agreement. It was his opinion that this requirement of mutual adjustment was fundamental and he went on to indicate a possible line of attack.

The whole discussion was a lively and stimulating experience, and we look forward to further such meetings. The Director in his closing remarks announced the next occasion as Monday, March 3, when Mr. L. G. Cameron would open a discussion on a paper entitled " Insolation in relation to cloudiness and cloud density " by B. Haurwitz.*

Subsequent discussions this session will be held on March 31 and April 21.

* *J. Met., Milton, Mass.*, 2, 1945, p. 154.

ROYAL METEOROLOGICAL SOCIETY

The Annual General Meeting of this Society was held on Wednesday, January 22, 1947, at 49 Cromwell Road, Mr Gordon Manley, President, in the Chair. The Council for 1947 was elected and the Symons Medal presented to Prof. D. Brunt, F.R.S., in recognition of "his outstanding original work in many fields of meteorology and his eminent services to our science in general as well as to this Society in particular", and of "his professional success both as teacher of students of many nationalities and as writer of an outstanding text-book embodying the first critical account, in logical and readable form, of the physics and dynamics of the atmosphere".

In his presidential address Mr. Manley drew the attention of the audience in view of the prevailing interest, to some recent Antarctic discoveries notably the unexpected height of the ice cap south-east of the Weddell Sea. Speaking as a geographer he then turned to the extent and character of the contributions to meteorology that the geographer could make. No would-be meteorologist should lack a sound mathematical and physical training at the undergraduate stage; but he suggested that the geographical attitude of mind was also worth cultivating. Hence if more contacts were to be made between physicists and geographers in some of our universities the production of graduates able to make useful contributions to meteorology would be encouraged. Through such contacts indeed many geographers with a knowledge of physics might also make useful contributions, especially with regard to many aspects of climatology in which there was still much room for development, and at a time when more independent university work was required.

LETTERS TO THE EDITOR

Extremes of Low Temperature

From time to time it happens that the thermometer reading of -23° F. at Blackadder (Berwickshire) on December 4, 1879, is resurrected as the lowest trustworthy reading ever recorded for the British Isles. It seems high time that the complete story was told.

The most authoritative comment on the reading is that of Alexander Buchan at the Half-Yearly General Meeting of the Scottish Meteorological Society on February 25, 1881.* In drawing attention to the fact that January 1881 had been colder than any of which they had previous record in Scotland, Buchan remarked that the greatest cold occurred at Springwood Park, Kelso, where the thermometer fell to -16° F. He went on to explain that the thermometer at Blackadder by which a temperature of -23° F. had been recorded in December 1879 was an exposed one and could not be taken into account in making comparisons with other places. It may be added that Buchan had inspected the Society's stations at Springwood Park and Blackadder between March and July 1880.

The reading of 1879 at Blackadder is mentioned in *Symon's Meteorological Magazine* of 1880, but the only other authority beside Buchan who need be quoted in detail is Marriott, Assistant Secretary of the Royal Meteorological Society.† Marriott was not content to accept the Blackadder report without

* *J. Scot. met. Soc.*, Edinburgh, 6, new series, 1901, p. 77.

† *Quart. J.R. met. Soc.*, London, 6, 1880, pp. 102-12.

further check and subsequently he asked for additional information from Dr. C. Stuart (former President of the Berwickshire Naturalists' Club). The resulting replies to specific questions were :—

The thermometer was an "upright registering thermometer".

It had been compared with another in the possession of Sir G. H. Boswell, having the scale engraved on the tube. The latter had been tested at Kew.

The "maker" was Lennie of Edinburgh.

It had a northern exposure, *2 ft. from the ground, with a sloping board about 2 in. across overhead, to keep off the wet.* It was mounted on a metal frame, painted white, a well-finished instrument (the italics are ours).

The observer was Mr. John Reid, gardener to Sir G. H. Boswell. He kept a regular register and sent returns to the Scottish Meteorological Society.

There was no mistake whatever made in the reading.

The site was open, with wood outside garden wall, and river Blackadder distant about 100 yds. The height above sea level was between 100 and 200 ft.

The thermometer was graduated to 30° F. below zero, with divisions on the frame.

The conclusions to be drawn from these notes are :—first, that the Blackadder readings should be rejected once for all, they were not obtained under reasonably standard conditions; and secondly, that so far as the statistics go there is nothing to choose between the extremes of low temperature in the Braemar district of the Cairngorms (— 17° F.) and the relatively flat Kelso district of Berwickshire (— 16° F.).

It seems desirable to ensure now also against the further publication of another low reading (— 26° F.) which has proved to be erroneous. This reading was said by local inhabitants to have been recorded by Baird and Barry in the Lairig Ghru (Cairngorms) during a blizzard which they did not survive. The reading has been published with reservations in the *Rothmill Quarterly Magazine*, *The Scotsman*, and the *Journal of the Royal Horticultural Society*, but so far as is known, nowhere else.

By the courtesy of Mr. Baird, senior, it has been possible to consult the actual diary of the journey. This establishes that the reading was + 6° F. (26 degrees of frost) on the night of December 28–29, 1927. The diary does not mention how the thermometer was exposed.

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NOTES AND NEWS

Rime in December, 1944 and January, 1945

Soft rime consists of ice crystals which are deposited on surfaces, especially on points and edges of all objects, in supercooled fog or mist and it is comparatively rare in our climate. Christmas Day 1944 was very cold with considerable fog at inland stations in England, and a quite unusual deposit of rime made the countryside exceptionally beautiful. These conditions persisted for some days.

At Stonehouse, Gloucestershire, on the 27th rime was observed to the tops of tall elms as well as on shrubs, palings, grass verges, roofs etc. ; on the 29th sunshine caused a partial thaw on the higher branches of trees and surfaces facing south, but severe frost occurred again on the morning of the 30th and the rime persisted for a while on small trees, shrubs and grass. The table gives the maximum, minimum and grass minimum temperatures at Stonehouse.

	December					
	25th	26th	27th	28th	29th	30th
	<i>degrees Fahrenheit</i>					
Maximum	29	28	32	35	35	39
Minimum	28	20	16	20	19	20
Grass minimum	17	13	9	14	11	15

It will be seen that the temperature did not rise above 32° F. for the three consecutive days 25th, 26th and 27th, while temperature fell to 16° F. in the air and to 9° F. on the grass on the morning of the 27th. Fig. 1 (facing p. 33) shows the deposit of rime at Downham Market (Norfolk) on December 27, 1944.

Photographs published in *The Times* of December 28, 1944, show similar conditions at Abinger, Surrey and at Cassiobury Park, Watford, while another published in *The Times* of January 3, 1945 indicates that the same conditions existed also near Dinant on the Meuse, Belgium. A photograph showing a similar deposit of rime at Sealand, near Chester, on December 15, 1928 is published in the *Meteorological Magazine* for February, 1929.

Another widespread period of rime occurred at the end of January, 1945, during an intensely cold spell which embraced the whole of the British Isles. The photographs, facing pp. 40 and 41, taken at places as far apart as Northern Ireland and East Anglia, indicate the exceptional nature of the phenomena.

From January 19 to 25 severe northerly gales brought arctic air over northern Europe, with periods of snow. As the wind moderated, the snow-covered surface cooled even further, with the development of mist and fog over a wide area. In eastern England, after a period of stagnation during which temperatures fell to between + 5° F. and - 5° F., a light easterly drift was established bringing in air off the sea with a surface dew point of about 25° F. The temperature rose gradually, with widespread fog and consequent deposit of rime. Fig. 2 shows the deposit at Linton-on-Ouse (Yorkshire) on January 24 and Fig. 3 the deposit at Allerton Park (Yorkshire) on the afternoon of January 25.

The photographs in Figs. 4 and 5 show conditions at Killadeas in Northern Ireland on February 1, 1945. No details are available, but it appears that following the cold weather which accompanied an anticyclone over the British Isles on January 29, light moist winds set in from the Atlantic with a gradually rising temperature. A number of photographs were obtained at Stonehouse (Gloucestershire) showing the rime deposit on trees, shrubs, etc. on January 26, following a period of intense cold and fog.

Acknowledgments are due to the officials (mainly at Meteorological Office stations) who kindly forwarded the large number of photographs from which these examples have been selected. All the photographs have been placed in the collection in the Library of the Meteorological Office at Harrow.

RAINFALL OF DECEMBER, 1946

Great Britain and Northern Ireland

County.	Station	In.	Per cent of Av.	County.	Station	In.	Per cent of Av.
<i>London</i>	Camden Square ..	1.95	82	<i>Glam.</i>	Cardiff, Penylan ..	4.66	93
<i>Kent</i>	Folkestone Cherry Gdns.	3.07	96	<i>Pemb.</i>	St. Ann's Head ..	4.31	91
"	Edenb'dg, Falconhurst	3.22	98	<i>Card.</i>	Aberystwyth ..	3.33	84
<i>Sussex</i>	Compton, Compton Ho.	4.61	110	<i>Radnor</i>	Bir. W.W., Tyrmynydd	8.31	101
"	Worthing, Beach Ho. Pk.	3.20	106	<i>Mont.</i>	Lake Vyrnwy ..	7.95	114
<i>Hants.</i>	Ventnor, Roy. Nat. Hos.	3.84	116	<i>Mer.</i>	Blaenua Festiniog ..	14.20	112
"	Fordingb'dg, Oaklands	3.48	88	<i>Carn.</i>	Llandudno ..	3.63	125
"	Sherborne St. John ..	2.81	85	<i>Angl.</i>	Llanerchmedd ..	6.15	140
<i>Herts.</i>	Royston, Therfield Rec.	2.04	88	<i>I. Man</i>	Douglas, Boro' Cem...	5.48	111
<i>Bucks.</i>	Slough, Upton ..	2.33	92	<i>Wigtown</i>	Pt. William, Monreith	4.83	106
<i>Oxford</i>	Oxford, Radcliffe ..	2.12	86	<i>Dumf.</i>	Dumfries, Crichton R.I.	4.86	114
<i>N'hant</i>	Wellington, Swanspool	2.21	94	"	Eskdalemuir Obsy. ..	6.53	93
<i>Essex</i>	Shoeburyness ..	2.05	111	<i>Roxb.</i>	Kelso, Floors ..	1.60	69
<i>Suffolk</i>	Campsea Ashe, High Ho.	2.81	122	<i>Peebles.</i>	Stobo Castle ..	3.56	94
"	Lowestoft Sec. School	3.05	131	<i>Berwick</i>	Marchmont House ..	1.92	68
"	Bury St. Ed., Westley H.	2.47	102	<i>E. Loth.</i>	North Berwick Res. ..	1.83	85
<i>Norfolk</i>	Sandringham Ho. Gdns.	2.78	109	<i>Mid'l'n.</i>	Edinburgh, Blackfd. H.	1.87	80
<i>Wilts.</i>	Bishops Cannings ..	2.46	75	<i>Lanark</i>	Hamilton W.W., T'nhill	3.90	90
<i>Dorset</i>	Creech Grange ..	4.35	99	<i>Ayr</i>	Colmonell, Knockdolian	5.48	98
"	Beaminsten, East St. ..	5.75	120	"	Glen Afton, Ayr San.	5.80	91
<i>Devon</i>	Teignmouth, Den Gdns.	4.36	103	<i>Bute</i>	Rothsay, Arden Craig	6.15	113
"	Cullompton ..	4.43	101	<i>Argyll</i>	Loch Sunart, G'dale ..	7.74	89
"	Barnstaple, N. Dev. Ath.	4.28	97	"	Poltalloch ..	6.02	94
"	Okehampton, Uplands	6.87	97	"	Inveraray Castle ..	9.78	98
<i>Cornwall</i>	Bude School House ..	3.66	84	"	Islay, Eallabus ..	6.89	116
"	Penzance, Morrab Gdns.	6.06	107	"	Tiree ..	5.18	99
"	St. Austell, Trevarna ..	6.57	108	<i>Kinross</i>	Loch Leven Sluice ..	3.71	94
"	Scilly, Tresco Abbey ..	5.33	114	<i>Fife</i>	Leuchars Airfield ..	2.24	91
<i>Glos.</i>	Cirencester ..	2.27	68	<i>Perth</i>	Loch Dhu ..	9.91	98
<i>Salop</i>	Church Stretton ..	3.69	110	"	Crieff, Strathean Hyd.	5.09	114
"	Cheswardine Hall ..	2.67	95	"	Blair Castle Gardens ..	3.97	104
<i>Staffs</i>	Leek, Wall Grange P.S.	4.43	118	<i>Angus</i>	Montrose, Sunnyside	3.63	131
<i>Worcs.</i>	Malvern, Free Library	2.14	77	<i>Aberd.</i>	Balmoral Castle Gdns.	2.88	85
<i>Warwick</i>	Birmingham, Edgbaston	2.87	107	"	Aberdeen Observatory	2.86	89
<i>Leics.</i>	Thornton Reservoir ..	2.55	95	"	Fyvie Castle ..	3.19	93
<i>Lincs.</i>	Boston, Skirbeck ..	2.49	116	<i>Moray</i>	Gordon Castle ..	1.72	64
"	Skegness, Marine Gdns.	1.74	79	<i>Nairn</i>	Nairn, Achareidh ..	.72	37
<i>Notts.</i>	Mansfield, Carr Bank	3.18	110	<i>Inv's</i>	Loch Ness, Foyers ..	2.77	63
<i>Ches.</i>	Bidston Observatory	2.66	100	"	Glenquoich ..	10.57	72
<i>Lancs.</i>	Manchester, Whit. Park	3.03	94	"	Ft. William, Teviot ..	7.90	77
"	Stonyhurst College ..	4.67	96	"	Skye, Duntuilum ..	5.29	85
"	Blackpool ..	3.96	121	<i>R. & C.</i>	Ullapool ..	3.50	57
<i>Yorks.</i>	Wakefield, Clarence Pk.	2.32	96	"	Applecross Gardens ..	5.45	85
"	Hull, Pearson Park ..	2.39	99	"	Achnashellach ..	7.87	83
"	Felixkirk, Mt. St. John	2.69	112	"	Stornoway Airfield ..	4.19	71
"	York Museum ..	2.18	97	<i>Suth.</i>	Lairg ..	3.66	91
"	Scarborough ..	2.83	119	"	Loch More, Achfary ..	6.56	71
"	Middlesbrough ..	2.04	105	<i>Caith.</i>	Wick Airfield ..	1.90	62
<i>Norl'd</i>	Newcastle, Leazes Pk.	2.24	95	<i>Shet.</i>	Lerwick Observatory	5.91	123
"	Bellingham, High Green	2.79	77	<i>Ferm.</i>	Crom Castle ..	4.35	105
"	Lilburn Tower Gdns.	2.22	84	<i>Armagh</i>	Armagh Observatory	3.82	122
<i>Cumb.</i>	Geltsdale ..	3.17	83	<i>Down</i>	Seaforde ..	4.62	112
"	Keswick, High Hill ..	7.74	116	<i>Antrim</i>	Aldergrove Airfield ..	3.71	108
"	Ravenglass, The Grove	7.08	155	"	Ballymena, Harryville	4.54	102
<i>West.</i>	Appleby, Castle Bank	3.90	98	<i>Lon.</i>	Garvagh, Moneydig ..	4.25	106
<i>Mon.</i>	Abergavenny, Larchfield	4.49	101	"	Londonderry, Creggan	5.85	134
<i>Glam.</i>	Ystalyfera, Wern Ho.	7.39	88	<i>Tyrone</i>	Omagh, Edenfel ..	5.55	131

WEATHER OF DECEMBER, 1946

During the first week of December the pressure distribution was of the usual winter type, with depressions near Iceland and an anticyclone over the Atlantic in latitude 30° to 40° N. ; there was also an anticyclone north and north-east of the Caspian Sea. A depression occupied the North Sea on the 3rd and 4th and another crossed the British Isles on the 7th to 10th, pressure falling to 963 mb. at Plymouth on the 8th. On the 11th areas of very high pressure began to move westwards across Russia ; 1060 mb. was exceeded north-east or north of Moscow on the 12th, 13th and 14th and in Norway on the 16th. These anticyclones extended their influence to France and the British Isles mainly from the 14th to 20th, while the main area of cyclonic activity lay far to the west and north. On the 23rd the eastern high pressure area retreated again to the Urals, and from then until the end of the month the Azores anticyclone re-appeared and depressions again passed from the neighbourhood of Newfoundland north-eastward across or to the south-east of Iceland. On the 26th pressure fell below 960 mb. north of the Faroes. In the Mediterranean depressions were unusually frequent, especially in the latter half of the month.

The chart of mean pressure for December shows a deep depression (below 992 mb.) in southern Greenland, where pressure was 8 mb. below normal. An anticyclonic belt of 1020–1025 mb. extended from south-eastern United States to Spain, and an intense anticyclone (1032 mb., 15 mb. above normal) lay over eastern Russia. In the Mediterranean mean pressure was below 1010 mb., a deficit of more than 5 mb.

The rainy weather which had characterised conditions in western Europe since the beginning of November gave way about December 14 to a period of dry cold conditions. A severe cold spell set in in Germany on the 15th, and according to *The Times* canals in western Germany were ice-bound by the 20th. These conditions spread to the British Isles, where severe frost was experienced at times from the 16th to 21st inclusive, particularly in England. The mean temperature for the week ending the 21st was 9° or 10° F. below the average in south and east England. On the morning of the 21st air temperature fell to 10° F. or below locally in northern districts of England. A shallow depression over Denmark moving west was associated with appreciable snowfall in south-east England on the 19th.

	AIR TEMPERATURE			RAINFALL		SUNSHINE	
	High- est	Low- est	Difference from average daily mean	Per- centage of aver- age	No. of days diff. from average	Per- centage of average	Per- centage of possible duration
England & Wales	°F. 55	°F. 8	°F. —2·5	% 101	+1	% 149	% 25
Scotland . .	54	15	—1·5	89	—2	129	18
Northern Ireland	50	18	—2·2	113	0	123	23