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AN EXPEDITION TO THE HIGH ANDES IN SOUTHERN PERU: SOME NOTES ON THE PARTY'S WEATHER LOG

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In 1956 a small British climbing party visited the high Cordillera Vilcanota, occupying a base camp about 5,050 metres (16,600 feet) above sea level at 13°51'S., 70°53'W., from 22 May to 4 July (southern winter). Three members, Messrs. J. Jewell, P. O'Donoghue and R. Whitling, sailing from Liverpool on the S.S. *Reina del Pacifico* in April, were joined in Peru by Mr. C. Darbyshire, a British mountaineer living in Lima. Jewell and Whitling had had Himalayan experience. Very few British expeditions have ever visited the Andes.

A small selection of meteorological instruments, chosen with an eye to portability, were loaned by the Meteorological Office. Because the area is so little-known meteorologically, considerable interest was taken in the weather observations which the party were able to make. The venture went without any financial grants from official bodies, but was supported by provisioning given free by several British and one Swiss firm through their agents in Lima. The party travelled by public transport, road and rail, the 900 miles from the port Callao near Lima to Sicuani over 3,500 metres up in the Vilcanota Valley, 70 miles south-east of Cusco. From this point the base camp was reached by a 3½ days' trek with hired mules up the mountain towards the Chimboya pass (5,235 metres), a route to the Amazon which is said to be never blocked by snow.

The Cordillera Vilcanota (see Plate I), of which the highest peak is Ausengate (about 6,400 metres), drops away steeply on its north-eastern side to the Amazon basin and the jungle. To the south-west between this area and the Pacific are other great ranges with peaks of similar height and extensive ridges above 5,000 metres, whilst about a hundred miles south-south-east is Lake Titicaca and the beginning of the broad Altiplano with its hundreds of miles of country above 3,000 metres in Bolivia and the borders of Peru. The nearest geographical and climatic analogies are with the Himalaya, Tibet and the lowlands of northern India and Assam, but the disposition of surrounding continent and ocean is quite different.

The base camp was on the floor of a high valley, half a mile wide, about two miles south-west of the pass and with snow-capped peaks rising directly above it (see Plate II). There is also an extensive ice-cap (Quenamari Ice Plateau) at 5,500–5,800 metres on the Cordillera south of the Chimboya Pass (see Plate III): the western edge of this hitherto unmapped ice plateau was surveyed by the expedition. There appeared to be evidence that the ice-sheet is receding.

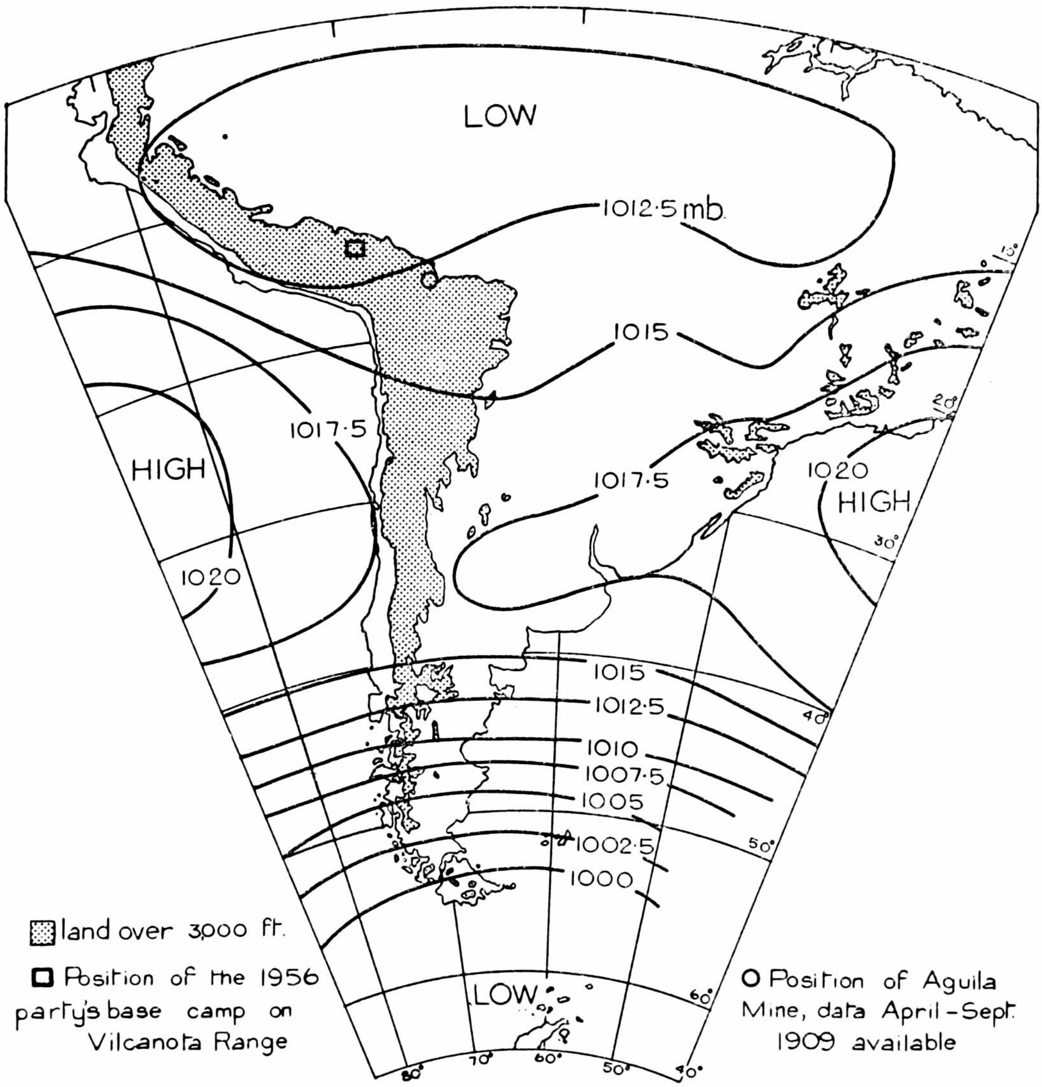

FIGURE I—NORMAL MEAN-SEA-LEVEL PRESSURES IN JUNE

Weather on the outward journey.—The voyage across the Atlantic between 10 and 18 April from Vigo, north-west Spain direct to Trinidad, passing near 29°N. 40°W., was made in constant south-westerly breezes without ever encountering the trade wind—an experience which is liable to occur at times when the usual Azores anticyclone is much displaced or nonexistent. Air temperatures, which had been 27° to 30°C. in the Caribbean and Panama, fell on the Pacific side as the equator was approached and the cold water of the Humboldt Current was encountered: at local noon on 25 April in 7°S. off the coast of Peru the dry-bulb temperature was 19°C.

Near Lima in the coastal desert strip in early May, and again on returning in July, the party experienced the thick low overcast, locally known as *garua*, which is a persistent winter condition there. At the end of April, however, the

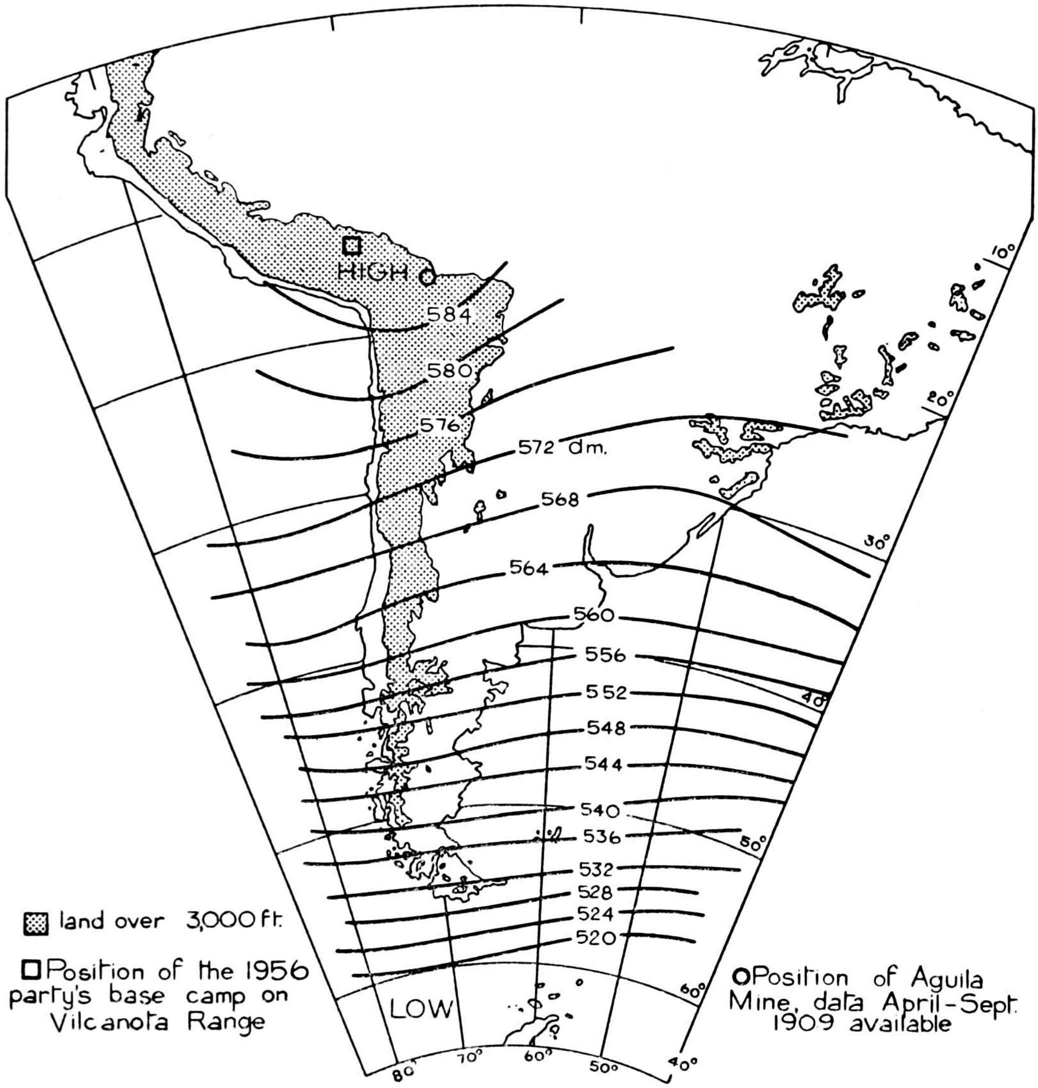

FIGURE 2—MEAN 500-MILLIBAR HEIGHTS (DEKAMETRES) IN WINTER

weather at Lima had been fine. The highway to Arequipa, Peru's second city (height about 2,500 metres above sea level), climbed through the low cloud into a region where the winter is pleasantly cool and sunny. Day temperatures at Arequipa were 20° to 22°C. Relative humidities almost constantly in the range 20 to 50 per cent pointed to the influence of subsiding air in this climate of the levels above the inversion, stratus and sea-breezes of the coastal strip. There is more rainfall in summer when thunderstorms are normally frequent over the mountains: the snow-line falls lower in summer in consequence.

In 1955–56 the summer rains had failed in the area about Lake Titicaca and the region was suffering from severe drought. Sunshine continued while the expedition was in the main Vilcanota Valley, though this valley running north-west between Sicuani and Cusco is narrow, well watered and agricultural in contrast to the arid Altiplano. The winds at these levels in winter normally blow from the north-east quadrant across the mountains from the Amazon side with frequent snowfall on that side of the peaks. Lightning was often seen from the base camp at night over the mountains to the north. The normal mean-sea-level pressure pattern in June and the average winter 500-millibar contours are shown in Figures 1 and 2 on which the position of the expedition's base is also marked.

Observations at the base camp on the Vilcanota range: 22 May–4 July.—Temperatures and humidities summarized in Table 1 were taken with a whirling psychrometer. Some days were missed when the party was out climbing, but in all cases observations on 30 to 40 days were included. The values undoubtedly give a reasonable impression of the prevailing conditions and of the range of variation, which was considerable in all items. The diurnal range of temperature clearly betokened fierce radiation at this height over a snow-free, dry surface: the average rise of temperature from 0800–1300 local time was about 8°C. and the range between the extreme air temperatures during the six weeks probably approached 30°C. Wind speed was observed by hand anemometer. Winds blew only up or down the valley. The wind direction showed no diurnal changes, being predominantly north—that is, down valley—at all hours of observation; however there was a spell of seven days from 10 to 16 June when the wind was consistently from the south and two other observations of south winds on the 18th and 23rd. Prevailing cloud amounts were small on the base camp (southern) side of the range, but much greater on the other side.

TABLE I—SUMMARY OF OBSERVATIONS AT BASE CAMP

(a) Air temperatures and humidities

	Local time	Mean	Highest	Lowest
		°C.	°C.	°C.
Air temperature ...	0800	0·7	10·0 (16/6)	−7·2 (3/7)
	1300	8·9	14·7 (27/6)	3·3 (29/5)
	1730 (about)	1·5	5·8 (31/5)	−3·6 (30/6)
Grass minimum temperature		−11·8	−5·3 (30/5)	−20·3 (4/7)
		%	%	%
Relative humidity	0800	74	100 (25, 26, 29/5 and 2, 3/6)	36 (15/6)
	1300	56	93 (30/6)	25 (14/6)
		mb.	mb.	mb.
Vapour pressure ...	0800	5·3	6·9 (24/6)	3·7 (8, 13/6)
	1300	6·5	13·9 (30/6)	3·0 (14/6)

Figures in brackets give the date of occurrence.

(*b*) *Percentage frequency of various Beaufort wind forces*

Time of observation (local time)	Beaufort force 0	1	2	3	4	5	6	7	8
					%				
0800	68	3*	16	5	3	0	0	0	0
1300	13	7	7	43	20	7	3	0	0
1730 (about)	21	5	41	18	15	0	0	0	0

* This figure should probably be amended to 8 per cent to take account of several mornings when wind speed was not recorded but in fact very light.

(*c*) *Percentage frequency of various (total) cloud amounts*

Time of observation (local time)	Oktas 0	1	2	3	4	5	6	7	8
					%				
0800	48	26	10	8	0	3	3	3	0
1300	10	33	10	13	13	13	0	3	3
1730 (about)	23	26	15	21	0	8	0	8	0

(*d*) *Prevailing cloud types (percentage of days)*

Time of observation (local time)	Cloud types: Cumulus, cumulonimbus or fractocumulus	Stratocumulus	Cirrostratus or altostratus	Cirrus or cirrocumulus
		%		
0800	11	16	18	8
1300	33	43	10	3
1730 (about)	26	39	3	3

Only the one predominant cloud type was entered at each observation.

Discussion.—Table II shows the course of the weather during the period at base camp. The variability noted in Table I is seen to have been to a considerable extent associated with different spells each of several days duration. The first week was cold, calm and moderately cloudy. 30 May to 3 June was a period of higher temperatures and unsettled, with maximum cloudiness and precipitation liability. There followed some clear, cold days with little wind. The period of southerly winds from 10 June brought, on the whole, the finest weather, the air being at first notably dry and of moderate temperature, but temperatures and humidities rose by the end of the spell to higher values than had been observed before: this period seems to have been used for most of the climbing and it may be presumed that the usual clouds were missing from the Amazon side of the mountains. The returning northerly winds from 24–30 June were stronger than before and brought high temperatures and high humidity. Temperatures fell sharply in the first days of July, apparently with lighter northerly winds, and there was rather frequent snowfall on the Amazon side of the mountains.

Observations, including direction of motion of cloud at various levels, were made between April and September 1909 at the mine Aguila (17°5′S. 67°15′W.; height 5,233 metres) (see Figures 1 and 2), near the top of the north-east face of the mountains at the edge of the broadest part of the Altiplano in Bolivia, by the German meteorologist Knoche. These observations, which relate to a point about 300 miles south-east of the present climbing party's base camp, have been

TABLE II—DAILY VALUES AT BASE CAMP
(Mean or range of three observations per day)

Date	Mean air temperature	Mean vapour pressure	Wind Direction	Wind Beaufort force	Mean cloud amount	Weather
	°C.	mb.			oktas	
May 23						10 cm. snow night of 22–23rd.
24	2·5	5·3	N.	0–2	3·0	
25	2·7	...	N.	0–2	4·7	
26	2·8	...	N.	0–2	2·3	
28	2·9	...	unknown	0–3	2·0	
29	2·6	5·6	unknown	3	2·0	
30	3·2	5·4	N.	0–3	5·7	Slight snow morning.
31	4·3	5·1	N.	0–3	5·3	¾ hr. snow afternoon.
June 1	3·9	5·0	N.	3–4	2·3	
2	3·2	...	N.	0–4	2·0	
3	4·4	5·9	N.	0–2	4·7	Hail twice in afternoon.
4	4·2	5·1	N.	0–4	0·7	
6	2·9	...	N.	0–3	0·0	
7	3·7	...	Calm		1·3	
8	2·7	3·5	N.	0–2	0·7	
9	1·8	5·1	N.	0–3	2·0	
10	3·6	4·1	S.	0–3	3·0	
11	3·9	3·5	S.	0–5	0·7	
18	6·8	6·8	S.	0–3	2·7	
23	5·3	7·5	S.2 became N.6		0·3	
24	5·5	8·2	N.	0–3	0·7	
26	6·8	...	N.	2–4	2·0	
27	6·2	5·3	N.	2–3	1·7	
28	7·2	8·2	N.	2–3	2·0	
30	5·4	...	N.	3–4	0·0	
July 1	4·0	...	N.	2–3	2·0	Snow morning of 2nd.

submitted to an interesting analysis by Flohn[1]. We know from this analysis that at Aguila the prevailing north-east wind was usually replaced by a down-slope (here south-westerly wind) at night, and that at 17°S. at no great height above the Altiplano the prevailing upper westerlies (actually blowing from west-south-west) were encountered. The high peaks south of about 17°S. are probably affected by prevailing west-south-west winds throughout the year, and in 23°S. climbers have reported that the peaks (5,750 to 6,750 metres above sea level) are liable to westerly storms "of fearful violence"—evidently associated with the subtropical jet streams of higher levels.

The Cordillera Vilcanota in Peru (13–14°S.) is probably too near the equator to come frequently within the régime of upper westerlies. Summit observations from El Misti (16°S. 71°W.; 5,850 metres) near Arequipa show 80 per cent northerly winds in winter, but more variable winds in summer with a small predominance of southerly (see Flohn[1]). The Vilcanota range probably enjoys a similar régime. The daily mean temperatures at the base camp suggest heights of the 500-millibar pressure level (5,800 to 5,900 metres) which must be always near the maximum of the daily distributions occurring over the Southern Hemisphere in midwinter, so that the alternately northerly and southerly air motion marks the passage of cell divisions in the belt of maximum pressure.

The expedition observations indicate

(i) very high levels for both 500-millibar pressure and the freezing level in this region and

(ii) a considerable magnitude of fluctuation during the six weeks.

From examination of the synoptic charts for each day published in the *Chilean Daily Weather Reports* it seems possible that the few occasions when precipitation fell on the south side of the Vilcanota range, and some of the other variations at the base camp, may be connected with trailing cold fronts penetrating the area from the south and west about 22, 31 May, 9, 22 June and 2 July: in most cases these disturbances were preceded by a day or two in which cirrostratus was in evidence and were followed by more stratocumulus. In all cases the snow or hail was accompanied by cloud noted as cumulus, cumulonimbus or nimbostratus. The case of 31 May was special in that precipitating clouds hung about for several days afterwards, and in the case of 22 June there was no precipitation reported. This general interpretation seems to have been first put forward by Coyle[2] and agrees with the general implication of one of the present authors' study of the Atlantic and African sectors[3]. All precipitation at base-camp level fell as snow or hail. Only once (22 May) was any appreciable depth reported: even then the snow soon melted in the next day's sunshine, though it continued lying two miles further up a valley directly north of the camp—this valley led to a glacier pass over the main Vilcanota range and down to the jungle.

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ERRORS IN THE GEOSTROPHIC VORTICITY CALCULATED AT 100 MILLIBARS

By D. W. MARTIN, D.Phil.

Summary.—The standard error in the geostrophic vorticity at 100 millibars in the neighbourhood of the British Isles, due to errors in the winds used in drawing the contour charts, is estimated to be about 10 per cent of the Coriolis parameter.

Introduction.—The geostrophic vorticity is normally derived from the field of contour height, and the errors in the calculated vorticity can be deduced if the errors in the contour heights used are known. However, it is not easy to assess the errors in contour heights interpolated from a contour chart since the contour lines give a partially smoothed field and are not drawn strictly to the height observations. The problem becomes acute at 100 millibars where the height observations contain serious errors. Fortunately, the 100-millibar wind can be measured with reasonable precision and due to the steadiness in space and time of the 100-millibar wind field, the ageostrophic components of motion are thought to be small. In consequence the gradients and directions of 100-millibar contour lines are drawn to the winds rather than to the heights. So, although the errors in the interpolated contour heights cannot be related to the errors of the observed contour heights, it is possible to estimate the errors of the drawn contour gradients from the known errors of the observed winds. In the following section, the finite difference formula used in calculating geostrophic vorticity from the contour height field is re-written in terms of gradients, so that the errors in the calculated vorticity may be expressed in terms of the errors of the observed winds.

Expressions for the vorticity.—The geostrophic relative vorticity on an isobaric surface is

$$\zeta_p = \left(\frac{\partial}{\partial x}\right)\left\{\frac{g}{l}\left(\frac{\partial h}{\partial x}\right)\right\} + \left(\frac{\partial}{\partial y}\right)\left\{\frac{g}{l}\left(\frac{\partial h}{\partial y}\right)\right\} \doteqdot \frac{g}{l}\nabla^2 h,$$

where g is the value of gravity, l the Coriolis parameter, and h the height of the isobaric surface, derivatives being in the isobaric surface.

It is customary to evaluate this expression by means of the finite difference approximation,

$$\nabla^2 h = \frac{1}{b^2}\Delta,$$

where Δ is $\sum_A^D h - 4h_O$, and is calculated from the contour chart, h_O and h being the contour heights at the centre O, and extremities A, B, C, D of a cross of semi-arm b (taken here in the order left, right, bottom, top).

If h is measured in hundreds of feet, and b in nautical miles at latitude 55°, then the vorticity thus calculated is

$$\xi = \frac{g}{lb^2}\Delta \text{ in units } 10^{-5} \times \text{sec}^{-1} : \qquad \text{...........(1)}$$

$g/lb^2 = 1$ and 2 for $b = 280$ and 200 nautical miles respectively.

Now, if U, V, are the components of the wind at the mid-points of the arms of the cross indicated by the suffices (α, β, γ, δ) then the geostrophic approximation gives

$$\frac{h_A - h_O}{b} = -\frac{l}{g}V_\alpha; \quad \frac{h_B - h_O}{b} = \frac{l}{g}V_\beta; \quad \frac{h_C - h_O}{b} = \frac{l}{g}U_\gamma; \quad \frac{h_D - h_O}{b} = -\frac{l}{g}U_\delta.$$

Since $\Delta = (h_A - h_O) + (h_B - h_O) + (h_C - h_O) + (h_D - h_O)$, we see that

$$\xi = \frac{1}{b}\left\{(V_\beta - V_\alpha) - (U_\delta - U_\gamma)\right\}. \qquad \text{...........(2)}$$

Expression for the standard error.—We write the true geostrophic vorticity as the sum of the calculated geostrophic vorticity, ξ, and an error, θ, and the true south wind at α as the sum of the wind given by the chart V_α (whether it is a reported wind or not) and an error εy_α, etc. Thus, analogous to (2), we have

$$b\,(\xi + \theta) = (V_\beta - V_\alpha) - (U_\delta - U_\gamma) + \varepsilon_{y\beta} - \varepsilon_{y\alpha} - \varepsilon_{x\delta} + \varepsilon_{x\gamma},$$

where, from (2)

$$b\theta = \varepsilon_{y\beta} - \varepsilon_{y\alpha} - \varepsilon_{x\delta} + \varepsilon_{x\gamma}. \qquad \text{...........(3)}$$

Similarly we may write the true vector wind at any point of the chart as the sum of wind vector from the chart, **Q** and an error **ε**. Thus

$$Q^2 = U^2 + V^2$$

and $$Q^2 + 2\mathbf{Q}.\boldsymbol{\varepsilon} + \varepsilon^2 = (U + \varepsilon_x)^2 + (V + \varepsilon_y)^2.$$

Subtracting, $$2\mathbf{Q}.\boldsymbol{\varepsilon} + \varepsilon^2 = 2U\varepsilon_x + \varepsilon_x^2 + 2V\varepsilon_y + \varepsilon_y^2,$$

so that $$2Q\varepsilon + \varepsilon^2 \geqslant 2U\varepsilon_x + \varepsilon_x^2 + 2V\varepsilon_y + \varepsilon_y^2 \geqslant -2Q\varepsilon + \varepsilon^2.$$

If it be assumed that the magnitude of the wind Q and its components U, V at any place are negligibly correlated over time with the corresponding errors ε, ε_x, ε_y, and in such a manner that, summing with respect to time,

$$\Sigma Q\varepsilon = \Sigma U\varepsilon_x = \Sigma V\varepsilon_y = 0;$$

then $$\Sigma\varepsilon^2 = \Sigma\varepsilon_x^2 + \Sigma\varepsilon_y^2.$$

If also the errors at different places on the charts are uncorrelated, and $\Sigma\varepsilon_{xy}^2 = \Sigma\varepsilon_{x\delta}^2$ etc., then squaring (3) and summing for all points O and for all charts examined

$$b^2\Sigma\theta^2 = 2\left\{\Sigma\varepsilon_x^2 + \Sigma\varepsilon_y^2\right\} = 2\Sigma\varepsilon^2,$$

and $$\frac{1}{N}\Sigma\theta^2 = \frac{2}{b^2}\frac{1}{N}\Sigma\varepsilon^2,$$

where N is the number of sets of variables summed.

Evaluation of the standard error.—Johnson[1] has shown, on the assumption that the vector errors in wind at any one point are independent of those at other points, that, in the neighbourhood of the British Isles, $\frac{1}{N}\Sigma\varepsilon^2 < (5\text{kt.})^2$ in summer, $(6\text{kt.})^2$ in winter, if the winds used are reported winds; and that $\frac{1}{N}\Sigma\varepsilon^2 < (6\text{kt.})^2$ in summer, $(7\text{kt.})^2$ in winter, if the winds used are interpolated from the reported winds.

Hence the root mean square error in geostrophic vorticity is

$$\left[\frac{1}{N}\Sigma\theta^2\right]^{\frac{1}{2}} = \frac{\sqrt{2}}{b}\left[\frac{1}{N}\Sigma\varepsilon^2\right]^{\frac{1}{2}}$$

$$< \frac{7\sqrt{2}}{3600}\frac{1}{b}\ \text{sec.}^{-1}$$

$$= 9{\cdot}8 \times 10^{-6}\ \text{sec.}^{-1}\ \text{for}\ b = 280\ \text{n.m.};$$

$$\text{or}\ 13{\cdot}8 \times 10^{-6}\ \text{sec.}^{-1}\ \text{for}\ b = 200\ \text{n.m.}$$

This is about 10 per cent of the Coriolis parameter at latitude 55°: while it should not obscure the vorticity pattern at any one point, it might obscure vorticity changes much less than 15 per cent of the Coriolis parameter.

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METEOROLOGICAL OFFICE DISCUSSION

The discussion held at the Royal Society of Arts on 17 March 1958 was on "The use of radar in forecasting precipitation", opened by Dr. P. G. F. Caton, and was followed by an informal talk on "Research in the Meteorological Office concerned with long-range forecasting", given by Mr. J. M. Craddock.

The use of radar in forecasting precipitation

Dr. Caton considered that there were two main uses of weather radar information:

(i) to prepare detailed forecasts of precipitation for particular localities for short periods ahead; and

(ii) to improve the accuracy of general forecasts, through the filling of gaps in the synoptic network.

He concentrated on the first aspect—the preparation and assessment of forecasts of the type: "Shower expected at 2.30 p.m., lasting 20 minutes; otherwise dry until 4 p.m.". The forecasts were prepared using the East Hill plan position indicator radar, for which the ranges of detection on moderate rain or showers are approximately 60–70 nautical miles, and on slight rain or showers 25–50 nautical miles.

Shower situations.—Considering first shower situations, Dr. Caton explained that the forecasts were prepared for a period determined by the expression

$$\frac{\text{distance of reliable detection upwind}}{\text{controlling wind speed}}$$

rounded to the nearest half-hour. Items in the forecast were of one of the forms:

(i) Dry—confidence *A*,

(ii) Shower expected, commencing . . . . , ceasing . . . . ,—confidence *A*, or

(iii) Shower may occur, with time information when justified—confidence *B*.

The forecasts were based on extrapolation of the motion of existing echoes, allowing for the uncertainty regarding the controlling wind and such changes in echo area as may reasonably be expected. Confidence *A* was aimed at whenever possible and no lowering of confidence was permitted on account of new echoes which might appear after the time of the forecast.

The controlling wind was either the latest 700-millibar wind from radar-wind soundings or, whenever possible, the wind deduced from the average movement of echoes approaching the target stations. A reliable wind could usually be deduced from echo movements over a half-hour interval, but it was necessary to maintain a continuous check on the wind direction; a $10°$ error in the estimated wind direction had a disastrous effect on the accuracy of the forecasts. The range of reliable detection from East Hill was arbitrarily assumed to be two-thirds of the range of the furthest echoes, subject to a maximum of 60 nautical miles.

The forecasts were prepared at half-hour intervals for Dunstable, Cardington (12 nautical miles north-east of East Hill) and Victory House (28 nautical miles south-east of East Hill). All of the forecasts were made in conditions when showers were present near the target station during the forecast period. They were from 29 dates, covering a wide variety of wind directions and strengths and shower frequencies, throughout the four seasons.

The forecasts were assessed by division into half-hour intervals and comparison of each interval with the actual conditions as indicated by the relevant autographic rain-gauge record. A shower was identified by its time of commencement and its duration. A shower forecast to commence in a half-hour interval was verified as regards occurrence by a shower commencing in that interval or in those immediately before or after; that is, an error up to 0·5 hour (and in some cases up to 0·9 hour) was accepted as being of timing only. The errors in the forecast times of commencement and duration were subsequently investigated. The results were presented in a series of slides, and can only be summarized here.

Duration-of-shower forecasts.—At Dunstable and Cardington 97 per cent of the forecasts were of at least one hour's duration. At all three stations 65 per cent of the forecasts were of at least two hours' duration and 38 per cent of the forecasts reached three hours' duration. The median durations were greater in summer than winter, due to the generally higher ranges of detection and lower average wind speeds in summer.

Forecasts of dry conditions.—Ninety-five per cent of the forecasts were correct in the first hour, 87 per cent in the second hour, 81 per cent in the third hour and 79 per cent in the fourth hour. A figure of 78 per cent correct was to be expected by chance during the test period. The differences between the results at the three stations were small. About one-half of the errors were associated with timing errors on showers forecast to commence or cease in an adjacent half-hour and the remainder to other causes, for example the development of a new echo.

Forecasts of showers.—Sixty-one per cent of the forecasts of "shower expected" were correct in the first hour and 50 per cent in the second hour. This category of confidence was inappropriate to forecasts in the third and fourth hours. Some 33 per cent of forecasts of "shower may occur" were fulfilled in the first, second, third and fourth hours. A figure of 26 per cent was expected by chance with application of the checking system. The proportion of showers occurring which were forecast either as "expected" or as "may occur" was 90 per cent, 59 per cent, 37 per cent and 19 per cent in the first, second, third and fourth hours respectively.

Variations in the accuracy of the forecasts.—The data were subdivided according to shower frequency and wind speed. A higher standard of forecasting was achieved on wet days than dry and for wind strengths of 6–50 knots compared with 5 knots or less. The poor results at low wind speeds were due to the importance of development and decay processes relative to the advection of existing echoes.

Timing errors.—These increased with time forward. Broadly, within the first two hours, two-thirds of the errors in the time of commencement and in duration were less than or equal to 0·2 hour.

Causes of error.—

(i) Shower occurring, not forecast. The main causes of error were development (80 per cent of cases) and use of a wrong wind (15 per cent of cases). The errors due to development were most frequent when the wind speed was less than 5 knots and the time of forecast was between 1200 and 1500 G.M.T.

(ii) Shower expected, did not occur. The principal causes of error were

(*a*) that the echo passed over the station without precipitation in the gauge (50 per cent of cases),

(*b*) use of a wrong wind (20 per cent of cases) and

(*c*) decay of the echo before reaching the station (30 per cent of cases).

The last-mentioned cause was relatively important in the second hour. The cases under cause (*a*) represented 21 per cent of the shower forecasts made. An investigation covering three summer months showed that slightly over 50 per cent of reported slight showers failed to record in an autographic gauge. If such very slight showers occurred in any of the cases above, the forecast which had been marked incorrect should have been classed correct. It was estimated that very slight showers occurred in at least one half of the cases and this led to substantial increase in the percentage correct of forecasts of "shower expected"—from 61 per cent to 74 per cent for the first hour.

Belts of precipitation.—Dr. Caton next considered forecasts involving belts of precipitation. These forecasts were prepared in an essentially similar way to those in shower situations. Items in the forecasts were of one of the forms:

(i) Dry—confidence *A*,

(ii) Rain expected to commence, to be continuous, to be intermittent or to cease, with times where appropriate—confidence *A*, or

(iii) Rain may commence, be continuous, etc.—confidence *B*.

The scheme of assessment was also similar to that for shower forecasts. Rain commencing or ceasing within 0·5 hour (and in some cases within 0·9 hour) of the forecast time verified the appropriate forecast and constituted a timing error.

Forecasts of the duration of belts of precipitation.—About 30 per cent of the forecasts reached two hours' duration at Dunstable and Cardington, but only 16 per cent did so at Victory House. The short durations compared with shower situations were due to the smaller ranges of detection and greater average wind speeds associated with precipitation belts. The durations were calculated by the formula

$$\frac{\text{distance of reliable detection}}{\text{700-millibar wind speed}}.$$

It was frequently possible to make accurate forecasts for longer periods by using the apparent speed of movement perpendicular to the belt. However, this assumed that the belt continued downward beyond the radar range.

Accuracy of forecasts.—Ninety-six per cent of the "dry" forecasts were correct in the first hour, 85 per cent in the second hour and 83 per cent in the third hour. About 70 per cent of the "rain to commence" and "rain to cease" forecasts were correct in the first hour and 40 per cent in the second hour. Confidence *A* was inappropriate to these forecasts in the third hour. About 75 per cent of the "rain to be continuous" forecasts were correct in the first two hours and 45 per cent in the third hour. Lower percentages were obtained for the confidence *B* forecasts.

Timing errors.—On average, the rain commenced 0·25 hour later than forecast. The bias was associated with a longer average duration of overhead radar echo compared with measureable surface precipitation. If an arbitrary correction of +0·2 hour were applied to all forecast values, 65 per cent of the errors would be less than or equal to 0·2 hour. One might reasonably expect to improve on this figure and to eliminate the arbitrary correction if information from a range–height radar display were also available. On average, the rain ceased 0·09 hour earlier than forecast. If an arbitrary correction of −0·1 hour were applied to all forecast values, 77 per cent of the errors would be less than or equal to 0·2 hour.

Dr. Caton next compared the accuracy of radar forecasts for belts of precipitation with those possible from a careful examination of hourly charts. On occasions when an identifiable area of precipitation was expected to reach Dunstable within six hours, the Central Forecasting Office had forecast the time of onset of the precipitation each hour until rain commenced. Their forecasts were checked against the Dunstable autographic rain-gauge record. The results indicated that the time of commencement of precipitation could be forecast two to three hours ahead with an average error of about one hour. For forecasts made one hour before the commencement of rain, the median error was 0·5 hour. The forecasts from synoptic charts could be made for a longer period ahead than those from radar, but within the radar range the latter were the more accurate. This was due to the greater ease of positioning the belt edges with a radar screen, and the elimination of the delay due to transmission and plotting of synoptic observations.

Summary.—Dr. Caton considered that, given an adequate range of radar detection, detailed forecasts of a useful standard of accuracy were possible for two hours ahead, both for forecasts of showers and of precipitation belts. Some accuracy was possible in the third hour. The two to three hour limit was imposed primarily by the development and decay of the echo pattern.

Discussion.—In reply to a question concerning the use of the 700-millibar wind, Dr. Caton explained that this was used only until a wind could be deduced from the actual movement of the echoes. He agreed that the wind at 850 millibars might be more appropriate in the case of snow showers.

Mr. Bradbury enquired concerning the results of forecasts of snow showers. Dr. Caton replied that the duration of such forecasts was generally short because of low detection ranges, but he did not think that the accuracy was necessarily less than for rain showers.

Mr. Wearmouth spoke of experience at Sylt using techniques similar to those of Dr. Caton. He thought that his timings of showers had not been quite as accurate as those presented.

Mr. Holgate asked whether difficulties could not arise through the radar beam intersecting different portions of the clouds at varying ranges. Dr. Caton replied that the practical difficulties were not significant with plan position indicator equipment having a vertical beam-width of 6°. The lower edge of the beam should normally be tangential to the earth's surface.

Mr. Bushby asked whether an echo was possible from clouds which were not precipitating.

Mr. Harper said that, except possibly with high-power 3-centimetre equipment, echoes would not be received from drops of less than raindrop size. The echo from a single drop was proportional to the sixth power of the diameter. It was possible to have echo without surface precipitation if the drops were held aloft by ascending air currents or if the drops were evaporating before reaching the ground.

Mr. Bushby then said that he was sure that echoes had been observed at Singapore from clouds which were not precipitating and which did not precipitate during at least the next two hours. A range–height indicator display had shown an echo base of about 4,000 feet.

Mr. Timms suggested that some of the echoes might have come from lee waves. He thought he had observed echoes from this cause using 3-centimetre equipment at Hemsby. Dr. Caton considered that this phenomenon had not occurred during his work, and Mr. Wallington pointed out that such echoes, if genuine, would remain stationary whilst convective echoes moved downwind.

Mr. Rackliff spoke of experiences at Uxbridge where radar information on storms moving from the English Channel at night had been particularly valuable.

Mr. Wallington asked whether the development or decay of echoes had been observed to occur in any systematic way, for example, on the low-pressure side of existing echoes. Dr. Caton replied that he had not noticed any such regularity. He had investigated the location of first appearance of non-forecast showers affecting Victory House in north-west winds, but had found no association with the Chiltern Hills. Radar could provide the tool for many investigations on the "mesoscale", but he did not think that underlying regularities would easily emerge.

Mr. Harper said that he was puzzled by the poor results for forecasts of showers at Cardington. He thought that this might be due to the fact that, in the prevailing south-west winds, the echoes were generally close to the radar site at the time of forecast and thus were sometimes from showers of smaller intensity than usual. Dr. Caton commented that two-thirds of the cases of overhead echo without measureable surface precipitation were at Cardington. He wondered whether there was some topographical feature affecting the rainfall from showers at Cardington.

Mr. Hunt spoke of his experience with the Decca radar scanner at Victory House. He stressed that 3-centimetre and 10-centimetre scanners would not detect fog or drizzle. He spoke of an occasion at London Airport when radar information had been most valuable, but commented that the conditions in this case were ideal as showers were forming only over the sea. He thought that the potentialities of radar should not be exaggerated.

Mr. Houghton remarked that the lifetime of many showers was only one to two hours. He thought that the forecast successes in the third hour must have been for showers associated with trough lines. He mentioned an occasion when the development and decay of rain areas had been observed on the Victory House radar in much greater detail than could be inferred from synoptic reports. In reply Dr. Caton said that Mr. Beimers at East Hill had found that the average lifetime of small shower echoes was about one hour. However, when conditions favoured heavy showers or thunderstorms, new cells tended to develop to replace those decaying and the life of the shower complex was considerably greater. Dr. Caton said that his results represented an average over a wide variety of conditions; the third hour successes were probably associated with heavy showers or thunderstorms. He agreed that the immediate and detailed observation of new developments was a most valuable use of radar.

Research in the Meteorological Office concerned with long-range forecasting

This account is concerned with some of the more important results of work carried out at Dunstable during the last four years. The item of most interest to most people is probably our experiment in monthly forecasting, but I must emphasize that this is only one item of a programme of systematic research into the slower variations of the atmosphere.

Our work proceeds from the standpoint that any predictable element there may be in the weather over long periods ahead is likely to be associated with the function of the atmosphere as the working substance of a heat engine, transferring energy from source regions in low latitudes near the ground to the sink regions mostly in high latitudes. This heat transfer is associated, mainly, with the planetary circulation which is most intense in the upper troposphere, and changes in the weather at the earth's surface are mainly the incidental consequences of the character and changes in the planetary circulation. Hence we should use as our basic variables for long-range prediction quantities which measure the intensity and position of the source and sink regions of the earth's surface, or are related to the character of the planetary circulation.

If we are to study atmospheric variations on the planetary scale, and wish to obtain results of statistical validity, then we must concentrate on those measurements which have been made regularly for many years over a network of stations extending over a large part of the earth's surface: the only such measurements are the rainfall and atmospheric pressure and temperature near the ground. In choosing where to start we rejected rainfall because its distribution patterns do not show the stability necessary in any element which is to form the basis for prediction, and air pressure because its claims seemed less strong than those of air temperature, which is more obviously connected with the thermodynamic processes of the atmosphere and which seems to have received less attention from earlier workers.

Choice of a time unit.—Our first objective was to study the patterns of temperature anomaly over as much as possible of the earth's surface. Before starting, however, we had to decide on our time unit. I thought that if we used data averaged over calendar months, we would probably lose in the averaging features which we ought to study, while using daily charts would entail too much paper work, so we compromised by using as our time unit the five-day period, of which 73 cover the year. We then faced the difficulty that before we can estimate anomalies, or departures from normal, we have to know what the normal is, and that although we can easily obtain monthly mean temperature normals for any number of stations, we cannot generally obtain normals for five-day periods. A satisfactory and objective method of overcoming this difficulty which has been described by Craddock[1,2] is by replacing each set of monthly mean temperatures by the best-fitting two-term harmonic form. When this work had been completed we were able to draw patterns of the five-day mean temperature anomaly pattern for the Atlantic half of the Northern Hemisphere, and this has been done as a routine since 1 May 1955.

Anomaly patterns.—The features of the first year's charts have been discussed by Craddock and Lowndes[3]. It appears that many areas of positive (or negative) anomaly are surprisingly intense, large in geographical extent, and often very persistent in time, lasting up to a month or two. Further work by Lowndes[4], has shown that the patterns of the surface air temperature anomaly when averaged over a month are very similar to corresponding patterns of the 1,000–500-millibar thickness anomaly which approximate to the departure from normal of the mean temperature distribution in the troposphere. The upper tropospheric air flow follows the mean tropospheric temperature distribution far more closely than it does the pressure pattern at the earth's surface, so the existence of persistent anomalies of air temperature at the earth's surface may be an indication of persistent anomalies in the planetary circulation. The identification of persistent anomalies of the general circulation may not be the whole solution to the problem of long-range forecasting, but if persistent anomalies occur, and the above evidence suggests that they do, then it is hard to believe that they are irrelevant to the forecasting problem.

One way of finding whether patterns of temperature anomaly are of any prognostic value is to match recent patterns with patterns from the past, and to see if the sequels show any similarity. We cannot do this for five-day mean patterns, because we have very little five-day mean data for back years, but we can for monthly mean patterns, because we can prepare monthly mean temperature anomaly charts for back years by using the data summarized in the *Smithsonian World Weather Records* and elsewhere. Our experiment was started to test this hypothesis, but before describing the experiment I must mention some considerations which apply to any and every system of analogue forecasting.

Analogue forecasting.—Forecasting by means of analogues is less elegant than arguing from general scientific principles, but it has the advantage that it can be used on problems so complex that we do not know which principles to apply. Further, if by an analogue method of forecasting we achieve a "better than chance" standard of success, we know that among the quantities we compare in choosing the analogues there is something which is related by physical processes to whatever we predict. Thus success in analogue forecasting may help us in our struggle toward general principles.

By using analogue methods, we avoid the mathematical difficulties of applying general equations to a particular case, and have the comforting knowledge that our forecast necessarily represents a possible state of the atmosphere, whereas no such certainty exists if general principles are applied in inappropriate circumstances. Against this we have the problem of handling, not a tidy and coherent set of principles, but a multitude of particular instances.

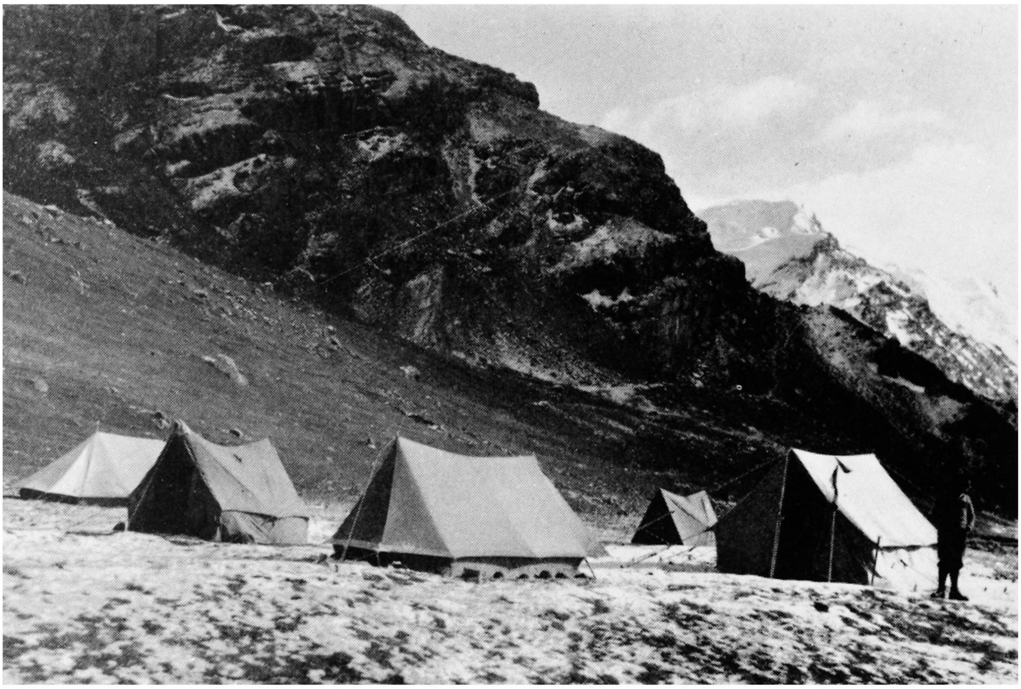
When discussing the possibilities of analogue forecasting it must be emphasized that there is never any possibility of matching a complicated situation in

Photograph by J. Jewell

PLATE I—THE VILCANOTA RANGE

View looking towards the Vilcanota range of the Andes near the expedition's base camp which was situated in a small side-valley to the left of the picture. The main valley here seen leads to the Chimboya Pass (5,235 metres) to the Amazon basin off the right of the picture. The general orientation of the range at this point is north-west to south-east and the picture is taken facing north or north-east. The cloud masses blowing against, and partly over, the mountains from the Amazon side are seen both in this picture and in Plate II.

(See p. 225)



Photograph by J. Jewell

PLATE II—BASE CAMP

The Andean expedition's base camp, 13°51'S. 70°53'W., about 5,050 metres (16,600 feet) above sea level, in the Cordillera Vilcanota in southern Peru. This camp was occupied by the party from late May to early July 1956. The peaks hereabouts rise to 5,750 to about 6,400 metres.

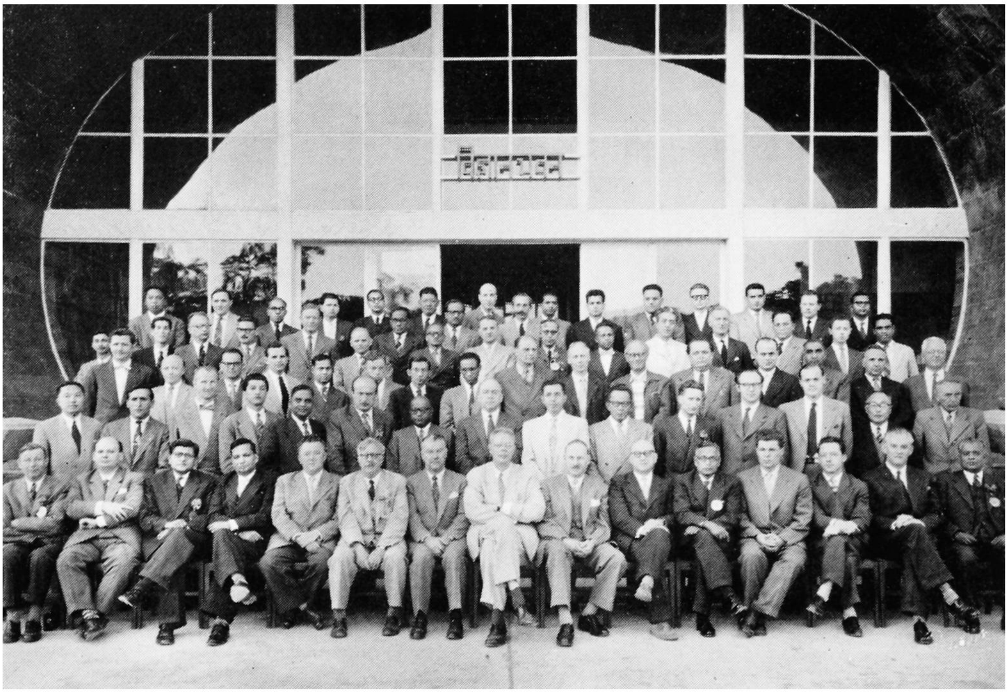
(See p. 226)

Photograph by J. Jewell

PLATE III—THE QUENAMARI ICE PLATEAU

General view of the south-west side of the little known Quenamari Ice Plateau at 5,500–5,800 metres above sea level in southern Peru (approximately 14°5′S. 70°50′W.). The picture was taken during the 1956 expedition looking east from a point south of the Chimboya Pass and six miles distant from the ice-sheet.

(See p. 226)



Photograph by Berry Studio, Delhi

SECOND SESSION OF THE COMMISSION FOR SYNOPTIC METEOROLOGY

Standing (Back row): U Hla (Burma), Harding (United Kingdom), Ananthakrishnan (India), Krepkogorski, *Interpreter*, Bhawan Ram, *Interpreter*, Po E (Burma), Soliman (Egypt), Walker (Ghana), Khan (Pakistan), Kabakibo (Syria), Naguib (Egypt), Durget (France), Pittavino (French Cameroons), Ribault (France), Das (India).

Standing (Second row): Bharucha (India), Ito (Japan), Ratisbona (Brazil), Grandoso (Argentina), Hannay (Australia), Klamer (Netherlands), Ramaswami (India), Lal (India), Sen (India), Bijvoet (Netherlands), Sengupta (India), Gadadhar (India), Montalto (Italy), Burnett (United Kingdom), Frolow (Madagascar), Nayakov, Nadarassin.

Standing (Third row): Rath (I.C.A.O.), Wusthoff (Germany), Haefelin (Switzerland), Snellman (U.S.A.), Pisharoty (India), Reeves (U.S.A.), Soontarotok (Thailand), Andualem (Ethiopia), Tschistiakov (U.S.S.R.), Thrane (Norway), Crone-Levin (Denmark), Desi (Hungary), Sallouhi (Lebanon), Mull (India), Koulakov (U.S.S.R.), Benum (Canada).

Standing (Fourth row): Chang (China), Inan (Turkey), Meyer, *Invited expert*, Navai (Iran), Koteswaram (India), Vesilovali (Turkey), Krishna Rao (India), Drouilhet (U.S.A.) Barbagallo (U.S.A.), Bunnag (Thailand), Mittner (France), Lonngvist (Sweden), Berggren (Sweden), Cheng (China), Ortmeyer (Germany).

Sitting: Ockenden (United Kingdom), de Sousa (Portugal), Mazumdar (Secretariat), Sundaram (Secretariat), Dufour (Belgium), Lugeon (Switzerland), Kutschenreuter (U.S.A.), Bleeker, *President*, McTaggart-Cowan (Canada), Leclercq (France), Basu (India), Logvinov (U.S.S.R.), Megenine (Secretariat), Boyden (United Kingdom), Mathur (India).

(See p. 249)

its entirety from past records. Indeed, the best we can hope for in most meteorological problems is to match approximately the values of four or five independent parameters or a rather larger number of interdependent ones. Hence the real problem of analogue forecasting is to decide on the essential features of any particular situation (these need not be the same in all cases) and to match these essentials as well as possible, while tolerating differences in features which have no prognostic value. To make progress with this problem our technique does not lay down hard and fast rules but includes the preparation for each past case of a much more complete description than can ever be expected to recur. The forecaster then has to use his judgement and experience in deciding the relative importance of agreement on different features.

The present experiment was to find whether, by matching the up-to-date pattern of the monthly mean temperature anomaly over a large part of the Northern Hemisphere with similar patterns from the past, it was possible to deduce anything useful about weather conditions over the British Isles during the coming month. The choice of the month as the time interval over which data are averaged was, as mentioned earlier, decided by the availability of data for past years, rather than on strictly scientific grounds. In trying to match a given monthly mean chart we restrict ourselves to charts for the same month in previous years, to ensure that the heat sources and sinks are about the same. This means that a current chart can be compared with not more than 100–200 earlier charts.

Selecting the analogues.—If a forecast is to be produced by the end of a calendar month, then the temperature anomaly pattern for that month must be estimated a few days earlier. This is done by using the five-day mean temperature anomaly charts, which are also intended for research purposes, an average being taken of as many as possible of those lying within the calendar month. The resulting chart (an average over 25 days) is usually a good approximation to the true monthly mean anomaly chart, at least as regards the positions and intensities of the main features. The current synoptic charts are also consulted as necessary to see whether any important changes are in progress during the last few days.

The work of producing the current monthly anomaly chart to time, which is basically a matter of extracting data from meteorological broadcasts made for synoptic purposes, is much the most laborious part of preparing these long-range forecasts. It would be made much easier if international agreement could be reached on an exchange of data for long-range forecasting purposes embodied in a short collective broadcast.

The selection of analogues from past years was originally carried out by scanning the tabulated data in the *Smithsonian World Weather Records*, a laborious and unsatisfactory process. It is now based on a very efficient edge-punched card index. One card is prepared for each calendar month, and on it are written the values of many meteorological variables during that month. The edge-punchings, when used in the way described later, enable us to choose from a pack of such cards all those in which the value of one of the variables lies in a particular range. The card is designed to receive the values of many more variables than can be matched from a limited number of past years, so that the forecasting possibilities of different groups of parameters could be compared. On the front it has spaces for the temperature anomaly at about 30 stations forming an open network over the area extending from the Rocky Mountains across North America, the Atlantic Ocean and Europe into Central Siberia. To each station on the card two edge-holes are assigned. If the anomaly on the card is negative, the first hole is cut open, while if the anomaly is positive the second hole is cut open. Thus, if it is desired to find from a pack of cards all those in which a particular station had, say, a negative temperature anomaly, a sorting needle is passed through the appropriate hole and the pack is lifted and shaken. All the cards which fulfil the condition will fall clear, while the remainder stay on the sorting needle. The cards falling clear can then be collected and sorted again on the anomaly at a different station.

The cards bear on the reverse a chart on the scale of 1:100 million, on which are plotted the temperature anomalies appearing on the front, and there is also a group of holes showing the year and the month, by means of which the pack can be got back into order after use.

The pack of anomaly cards was originally completed for the years 1881 to 1940, and is kept in 12 sections, one for each calendar month. When a chart for the current month, say, September, has been prepared in the way described already, a choice is made, out of the stations which appear on the anomaly cards, of a few which represent the most important features on the current September chart. The pack of the September cards for previous years is then sorted on these key stations, in turn, in order of importance. Since only the cards which agree on the first station are sorted on the second, the number of cards remaining is reduced at each sorting, but it is a mistake to continue fitting more and more stations until only a single analogue is left. Better results are obtained by stopping sorting when at least five to ten cards remain, and giving individual attention to each of these.

The charts on the reverse of the anomaly cards were intended to allow a detailed comparison between cases. They have not proved adequate for this purpose, because owing to the small scale and the wide spacing between stations, patterns may appear to be similar although closer examination reveals important differences. However, the card index is an excellent device for reducing the original list of years to perhaps a dozen or fewer which are possible analogues. These cases are then examined in greater detail. For each of them the temperature anomaly pattern is drawn on a much larger scale (1:30 million) using data for as many stations as possible. In the final choice among analogues, the comparison is extended to include the synoptic weather sequences over the eastern Atlantic and western Europe as well as the temperature anomaly pattern. This is logical, because agreement between synoptic weather sequences is evidence that the similar temperature anomaly patterns were arrived at in the same way, by similar changes in the upper air flow.

The choice of the best among a group of possible analogues is a matter for personal judgement. In matching anomaly charts, more weight is placed on agreements in the better-marked features of the patterns than on agreements in absolute magnitudes of the anomalies and more on agreements within the home sector (extending, say, from Labrador to the Urals) than on agreements in more distant regions. In matching synoptic weather sequences agreement is sought only in the features related to the state of the general circulation, while differences which can occur with the same pattern of general circulation are disregarded. In practice the choice is made by a panel of three or four meteorologists, who examine all possible analogues, and then follow a principle of exclusion, weeding out the least satisfactory until those which remain are of about equal merit.

The next step is to examine the weather sequence and the temperature and rainfall characteristics of the next month in the British Isles in each of the analogue years. Sometimes these sequels show a good deal of agreement among themselves, and then the forecast will be that the features which show agreement will recur. More often, the sequels vary considerably among themselves. The forecasters may then go over their analogues again and try, by applying more rigid criteria, to reduce the group until it shows some measure of consistency, or their forecast may follow the average or modal conditions of the group of analogues.

Although the selection of analogues depends so much on personal judgement, if the process is carried out independently on the same case by different forecasters, their selections are usually in good agreement. If the selection is made as we usually do, by scientists in consultation, the choice is not, of course, unique or infallible, but it has the same type of validity as a medical diagnosis made by an experienced physician or an analysis of a synoptic chart made by a practising forecaster. The most difficult problem is apt to arise at the next stage, when the forecasters may have to decide what if anything can safely be deduced from a number of analogues in which the subsequent weather developments vary a good deal from one case to another. Such divergences are evidence that the similarities between the analogues are not in themselves sufficient to determine the future developments, and the bigger the divergences are, the wider the margin of uncertainty which must be attached to any forecast based on such similarities. It is conceivable that the divergences might be so large that the forecasting panel would conclude that no useful deduction of any kind could be drawn from the analogues; however, this possibility has not occurred during the 29 months since the start of the experiment.

Example of forecasting techniques.—A good example of the technique is provided by the forecast for March 1957 prepared on 27 February 1957 in the following terms.

"*Forecast for March* 1957

The best analogues for the temperature anomaly pattern in February 1957 seem to be 1882, 1894, 1903, 1915 and 1935. These suggest mean temperature above normal and rainfall below normal at London.

Normal London temperature in March ... 42·2°F.

Normal London rainfall in March ... 41 mm.

Comment

The principal features of the temperature anomaly chart for February 1957 are a warm area over Europe, cold areas over south Greenland and the Atlantic and warm areas over the United States and east Canada.

Four of the five analogue years were warm (in March), the remaining one having near normal temperatures. Four of the years were dry, the other having slightly above normal rainfall.

In all of these years pressure was high near the British Isles for a large part of the month (March). Examination of the synoptic types suggests that there will be considerable periods with an anticyclone centred over or near the British Isles, but that there will also be periods with westerly winds. During the latter, however, pressure will remain relatively high in the south of the country and rainfall will probably be light in the south-east.

During the anticyclonic period, wind directions are uncertain but direct northerly outbreaks from the Norwegian Sea seem unlikely."

For comparison with this statement, made before the event, a scientist not otherwise connected with the experiment summarized the actual weather as follows:

"Exceptionally mild weather during the first fortnight was replaced by wetter though still mild weather on the 14th. During the last three days of the month temperatures fell steadily and although cloud increased, the weather was dry. Mean London temperature well above normal; rainfall below normal."

This example shows many of the difficulties and possibilities inherent in the problem.

The anomaly patterns for 1957 and the five chosen analogue years are shown in Figure 1. In each of these years there was also, in February, some similarity in the general synoptic sequence of weather over the British Isles: there were other years which might have been included on the strength of the anomaly patterns alone, but which showed no real resemblance in the synoptic weather sequence.

Once the forecaster has selected the possible analogues he has to decide how much he can safely say about the features which all or most of these years have in common. It follows that the forecasts differ a good deal in content from one month to another, depending on the number and goodness of the analogues, and also on the experience of the forecaster.

With forecasts having a period of validity as long as a month, the sum of personal experience mounts very slowly, and even the forecasters who have taken part in the experiment from the beginning have carried out forecasts for only a few of the possible monthly weather situations. It follows that each forecast, as it is made, is something of an experiment, and that when faced with a difficult situation a forecaster may have to rely on some argument which he has never used before and which may or may not be justified in the event. For these reasons it is difficult to produce a method of verifying monthly forecasts which will measure anything except the standard attained on some particular date. However, a comparison between the forecast and actual temperature anomaly and percentage rainfall anomaly at London for each month from the start of the experiment up till July 1957 is shown in Figure 2. The results are put in numerical form in Table I.

It appears from Table I that over these 27 months the method has had a degree of success significantly higher than the chance expectation, and that practically no contribution to this success has been made by "persistence". These figures may be compared with those published by Hofmann[5] for the similar experiment which is being carried out in Germany. The problem of checking long-range forecasts is one which troubles all workers in this field, and I do not regard the correlations as necessarily telling the whole truth. Nevertheless I do not think we should be dissatisfied with our results so far.

TABLE I—CORRELATIONS BETWEEN FORECAST AND ACTUAL TEMPERATURE ANOMALIES (r_{AF}) AND BETWEEN "PERSISTENCE" FORECASTS AND ACTUAL ANOMALIES (r_{AP}) FOR TEMPERATURE AND RAINFALL AT GREENWICH FOR THE 27 MONTHS OCTOBER 1955 TO DECEMBER 1957

	r_{AF}	r_{AP}
Temperature	+·46	+·03
Rainfall	+·41	−·01

Analogues used in recent forecasts.—An interesting result is shown in Table II, which gives the number of times that a year from a given decade has been chosen for an analogue for a month in the years 1956 and 1957. The total number of analogues chosen was 56, and if these had been equally likely to come from any decade, the expected number per decade would be 9·3. Table II shows that most analogues were chosen from the earlier years 1881 to 1910, and it is easy to show, by the χ^2 test that if all years were equally likely to be chosen, discrepancies as great as these would occur in fewer than one in one hundred trials.

TABLE II—THE OCCURRENCE BY DECADES OF ANALOGUES FOR MONTHS OF THE YEARS 1956 AND 1957

Decade	Number of analogues
1881–1890	19
1891–1900	10
1901–1910	11
1911–1920	8
1921–1930	3
1931–1940	5
Total	56

It seems probable therefore that a temperature anomaly pattern of the 1950's is more likely to be matched by a pattern from the 30 years 1881 to 1910 than it is by a pattern from the years 1911 to 1940. This result would be expected if, as has been suggested on other grouds, the climate passed through a stationary state in the period 1921 to 1940, and the present conditions resemble those preceding the optimum rather than conditions during the optimum. Even if this is a bit far-fetched, the figures certainly suggest that the years which are likely to be analogues are grouped together in time, so that the decades 1861 to 1880, and the most recent years 1941 to 1957 may prove more fruitful sources of analogues than the years 1911 to 1940.

Present day development and research.—Before leaving the monthly analogue forecasting I should mention that work is going ahead as fast as possible to develop and improve the present technique. The main lines are:

(i) The collection of temperature data for more years, so that analogues can be chosen from the largest possible field.

(ii) The collection of other data such as atmospheric pressure values to see whether they will yield any information besides what we get from the temperatures.

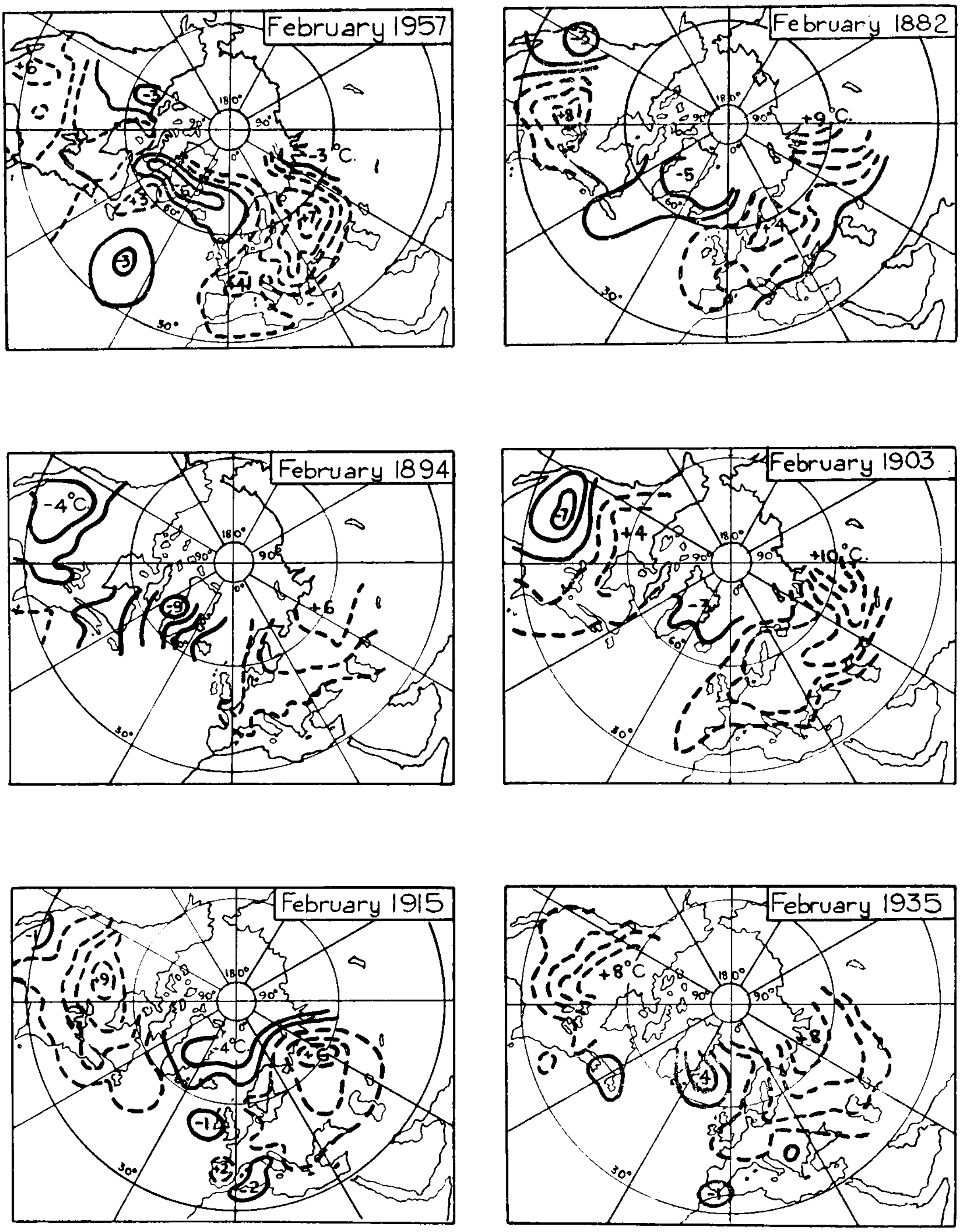


FIGURE I—TEMPERATURE ANOMALY PATTERNS FOR FEBRUARY 1957 AND FIVE ANALOGUE YEARS

The isopleths are for odd numbers of degrees

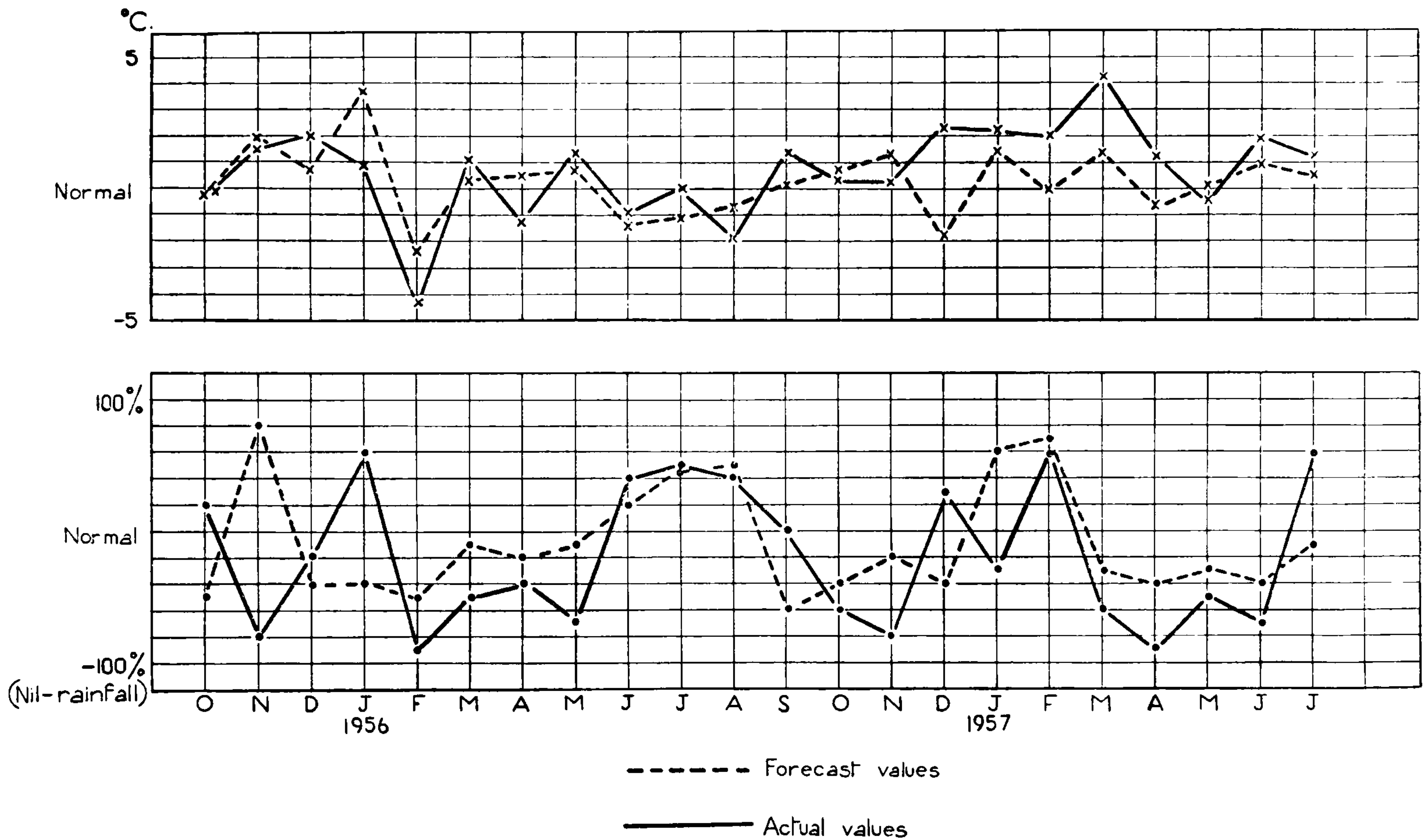


FIGURE 2—EXPERIMENTAL MONTHLY TEMPERATURE AND RAINFALL FORECASTS AT LONDON, OCTOBER 1955–JULY 1957

(iii) The preparation of a forecaster's brief, describing every outstanding month during the 108 years since 1850 with hints as to how it might have been forecast.

(iv) The collection of data to enable the system to be used to produce forecasts for periods other than calendar months.

Apart from this work which is going on within the Directorate of Research, the Director-General of the Meteorological Office has initiated a form of consumer research. The present experimental forecasts contain as much or as little detail as the forecasters think can, in each particular month, be inferred from the analogues. The questions whether this is the information required by any particular user, and whether the standard of accuracy attained is good enough to benefit the user cannot be answered by research within the Meteorological Office. To answer these questions the experimental forecasts are now being circulated in confidence to a number of authorities (outside the Meteorological Office) who are representative of various classes of potential users. These authorities have agreed to comment on the forecasts received during a period of, say, a calendar year, and future work will take account of their suggestions.

The monthly forecasting experiment is, of course, not the only research project in the field of long-range forecasting. It is an attempt to get to grips with the problem at the most convenient place while work proceeds on other projects of a more fundamental character which require more time spent on them before they can be expected to show a useful return. Among such fundamental projects I should mention one described by Gilchrist[6] who set out to apply numerical forecasting methods over the longest possible time scale by the use of spherical harmonics, and another described by Houghton[7] who set out to find what variations of the state of the earth's surface were capable of making a significant difference to the heat economy of the atmosphere. My own efforts to tackle fundamental questions have been concerned, largely, with the statistical problem. "What period of validity should we use if our long-range forecasts are to have the best prospects of success?" This leads to another: "Given a geophysical time series, with no prior knowledge of the processes generating the series, how should we set about analysing the series to learn as much as possible about the generating processes?" A first attempt which has been described by Craddock[8] involved calculating the correlation between the temperature at Kew on each calendar day with those on each of the seven following days for every day of the year. This investigation showed beyond doubt that the time series we had to study might be non-stationary, in the sense that their statistical properties varied from one time of year to another. This meant that we could not rely on methods such as those described by Wiener[9] which deal only with stationary time series. After considering several alternatives, I arrived at the idea of analysing the time series with a set of mutually exclusive band-pass filters. The result of this analysis, which has been described by Craddock[10, 11] is that the original series is resolved by linear operations into a series of components uncorrelated with one another and each composed of oscillations lying within a definite restricted wave-band. It is easy to calculate what the average amplitude of the oscillations in each wave-band should be, on the assumption that the original series is of a random nature, and if the actual amplitude of the oscillations in some wave-band is much larger than the chance expectation there is a presumption that some process is at work tending to generate oscillations in that wave-band. The method was applied to analyse the temperature variations at Kew with periods lying between two days and 50 years and showed that, apart from the annual variation the periods of the oscillations of largest amplitude tended to cluster in one of two ranges, namely, about ten days and near 30 days. The oscillations on longer time scales become progressively smaller.

The extension of this work to other meteorological variables, and to data for other stations should enable us to isolate and study the features which matter to the long-range forecaster in a way which has been impossible hitherto.

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WORLD METEOROLOGICAL ORGANIZATION

Second Session of the Commission for Synoptic Meteorology

Five years after its opening session in Washington, the World Meteorological Organization Commission for Synoptic Meteorology met for the second time on 21 January 1958. The conference was held at New Delhi and lasted for four weeks, with a total of over 70 representatives from 36 countries. The United Kingdom delegation consisted of Messrs. Boyden, Harding and Ockenden from the Meteorological Office and Instr. Capt. Burnett from the Naval Weather Service.

All meetings took place at Vigyan Bhavan, a spacious building designed for such gatherings and lavishly equipped for the purpose. The Minister of Transport and Communications welcomed the delegates on behalf of the Government of India and the conference then settled down to its work under the presidency of Dr. W. Bleeker. Dr. S. Basu, the Director of the Indian Meteorological Service, was elected his deputy for the duration of the session.

As at the 1953 session, three committees were established. One was concerned with codes, another with telecommunications and the third with matters falling under neither of these headings. A number of items were inevitably considered by more than one committee.

The approach to code problems was somewhat circumspect, and many meteorologists will be relieved to know that the conference was opposed from the start to any major changes. Machine-handling of data for climatological purposes is already so far advanced that discontinuities in coding procedure should not lightly be introduced. There was, moreover, the background thought that increased mechanization in forecasting might ultimately call for fundamental changes in the form of the transmitted message, and for this reason piecemeal changes at the present time were best avoided. With such considerations in mind the Commission decided to establish a working group on codes which is to report to the Third Session, but it was made clear that the working group should not attempt to justify its existence by the number of changes it recommended. By way of light relief from more serious cogitations, the suggestion was made that the working group might begin by clarifying $C_s = 6$ in Code 15, whereby the International Analysis Code makes provision for the cloud system defined as "Depression with misty tail".

Some minor changes in codes were made to bring Volume B of World Meteorological Organization Publication No. 9, the handbook on which national coding manuals are based, into line with the 1956 edition of the *International Cloud Atlas* (which covers more elements than its title suggests). There was some extension of the International Analysis Code and of the flight forecast codes, primarily to allow for the inclusion of more information in the region of maximum winds, and the conference endorsed the code for the nature of the tropopause which had been proposed by the Commission for Aerology.

A code was adopted for the transmission of supplementary reports by ocean weather ships and broad criteria were set out for the making of such reports. This introduces little or no change from present procedures by British ships. The messages will be preceded by the word SPESH, since neither MMMMM nor BBBBB is appropriate to a report which is of synoptic rather than purely aviation significance. An alternative proposal was made for 1½-hourly reports, giving 16 equally spaced observations a day, but this received little support.

The 100-millibar surface was added to the list of "mandatory levels" transmitted in upper air messages, and preferred levels were decided upon for the high atmosphere. With increasing heights being attained by radiosondes there is a need for standardization in the levels for which charts are drawn, and the Commission recommended that countries should concentrate on 150, 70, 50, 30, 20 and 10 millibars. With 100 millibars these levels give a roughly uniform height distribution up to over 30 kilometres.

An attempt was made to resolve the differences in reporting visibility. In preference to the recognized "minimum visibility" of the international code a number of countries at present report some form of average visibility, which of course differs from the minimum whenever visibility varies with direction. Both forms of report are firmly established procedures and in the hope of eventually removing the anomaly it was proposed that work be undertaken to obtain further information on the directional differences of visibility that exist at a number of aerodromes.

There was an interesting discussion on what was the best time to release radiosonde balloons so that the readings should most nearly synchronize with surface synoptic observations. The compromise adopted was that the balloon should be near the 500-millibar level when the corresponding surface synoptic observation was made, and therefore was best released within the half-hour preceding that observation. A latitude of 15 minutes at either end of this period was agreed upon, one object being to permit release by observers who have just made and transmitted a surface observation at the synoptic hour.

The telecommunications committee spent most of its time considering the Final Report of the Commission for Synoptic Meteorology Working Group on Telecommunications which met in Paris in October of last year, under the chairmanship of Mr. Ockenden. Further impetus was given to the replacement of wireless telegraphy transmission by radio-teleprinter and facsimile, and a satisfactory measure of agreement was reached on the standardization of equipment and procedures. An outstanding recommendation which was adopted after detailed study by a working group was that a scheme should be introduced for the rapid exchanges of observations around the hemisphere. This would be obtained by means of a chain of five stations around the globe which would be connected by land-line or radio-teleprinter, each being responsible for the transmission of surface and upper air reports from an extensive area and for the dissemination within that area of reports collected by the other four stations. The aim of the scheme is to make available quickly and regularly enough material for the construction of circumpolar charts for the Northern Hemisphere.

Towards the end of the session Mr. P. H. Kutschenreuter, the leader of the United States delegation, was elected as the new President of the Commission, with Dr. S. N. Sen, of India, as Vice-President.

Everyone was impressed with the organization of the conference and the efficiency with which the thousands of documents were circulated as the session progressed. There was much appreciation, too, of the personal assistance given by the staff of the Indian Meteorological Department and the way in which they ensured that delegates made the most profitable use of their very limited free time. Such highlights as the celebrations of Independence Day, the visit to the Taj Mahal and attendance at a Presidential garden party were unforgettable events. A visit was also made to the New Delhi Meteorological Office, where among other things the delegates saw the complete manufacture of radiosondes, and in the last week the Minister of Civil Aviation entertained the delegates to a farewell dinner, which took place in an atmosphere appropriate to the occasion.

REVIEW

Artificial stimulation of rain. Proceedings of the first Conference on the physics of cloud and precipitation particles, held at Woods Hole Oceanographic Institution, Woods Hole, Massachusetts, 7–10 September 1955. Edited by H. Weickmann and W. Smith, 10 in. × 7½ in., pp. xvi + 428, *illus.*, Pergamon Press, 4 and 5 Fitzroy Square, London, W.1. 1957. Price: £5 5*s*.

The first and perhaps the most important comment to pass on this book is that its main title of *Artificial stimulation of rain*, which is the only one to appear on the cover, is grossly misleading. Out of forty-nine papers and discussions only two have any connexion with the artificial stimulation of rain and neither of these gives an account of new work: both in fact provide summaries and discussions of aspects of work that have been written up in greater detail elsewhere—a comment applicable to many of the other papers as well. The first gives an account by Fournier d'Albe of the cloud-seeding trials in Pakistan using common salt, and the second by Braham and Sievers describes the overseeding of cumulus clouds with dry ice. There are no papers on seeding with silver iodide of either cumulus clouds or layer clouds, whether by aircraft or by generators on the ground; such papers are certainly to be expected in a book with the present title since most attempts at commercial or economically valuable rain-making in middle latitudes make use of silver iodide.

The book is divided into six parts covering respectively:

(i) Aerosols: their origin, distribution and measurement (13 papers).

(ii) Condensation and coagulation; measurement of cloud- and rain-drop size; rain from water clouds (13 papers).

(iii) Melting and freezing; studies of snow and ice in the generation of precipitation (12 papers).

(iv) Crystal growth and nucleation; laboratory and field studies (9 papers).

(v) Thunderstorm electricity (1 paper).

(vi) International terminology (1 paper).

The first part has one paper on meteoritic dust by Schaefer and another by Junge; these offer no support for the well known theory of E. G. Bowen. The second part is interesting in that it shows how the realization of the importance of collision processes in the formation of rain has grown in recent years. The third and fourth parts contain interesting and beautiful photographs illustrating the freezing of droplets and crystal growth.

The general impression produced by the book, as with most published conference proceedings, is of patchiness and incompleteness. Many papers describe aspects of work dealt with more fully elsewhere, and others describe work in an incomplete form. In view of this, the lavish and glossy production by the Pergamon Press and the very high price of five guineas seem to the reviewer to be quite unjustified; a much cheaper reproduction of typescript would have sufficed.

R. P. WALDO LEWIS

HONOUR

Award of the International Meteorological Organization Prize to Mr. Ernest Gold

At its tenth session in Geneva this year, the Executive Committee of the World Meteorological Organization awarded the International Meteorological Prize for 1958 to Mr. Ernest Gold, formerly Deputy Director of the Meteorological Office. The previous awards were made to Dr. M. Hesselberg (1956) and to the late Professor Rossby (1957).

The I.M.O. Prize was created by the Second Congress of W.M.O. in 1955. The Prize consists of a gold medal, a substantial sum of money and a certificate giving the citation of the award, bearing the signature of the President of W.M.O. and the official seal of the Organization. The award is made annually by the Executive Committee by selection from names proposed by Member countries and it is laid down that "in the selection of the recipient, both scientific eminence and the record of work done in the field of international meteorological organizations should be taken into consideration". The inscription on the medal "Societas Gentium Meteorologica. Pro singulari erga scientiam meteorologicam merito" expresses this thought most concisely.

Those who know Mr. Gold's long and distinguished career in meteorology will readily agree that no one could be better qualified to receive this award. He was the first to explain the existence of the stratosphere by mathematical analysis and his memoir on "Barometric gradient and wind force" is among the classics of meteorology. Equally famous among professional meteorologists is his work for the organization of forecasting, and the Gold Slide and the Gold Visibility Meter bear witness to his skill as a designer of instruments. In international meteorology his record is outstanding. He was President of the Commission for Synoptic Weather Information of the I.M.O. from 1919 until he retired from the Meteorological Office in 1947, and he was also President of the Meteorological Subcommission of the International Commission for Air Navigation (the forerunner of the present International Civil Aviation Organization) from 1922 to 1946. During this period he did much to formulate the present international meteorological codes.

Mr. Gold is well known to the staff of the Meteorological Office, both as a member of the Meteorological Research Committee and as a frequent attender at the "Monday Discussions". His long experience and vast range of knowledge make his contributions unique, and his wit is as incisive as ever. His many friends, both in the Meteorological Office and the wider circle of international meteorology, will rejoice that a life-long service to the science of the atmosphere has been recognized in so fitting a manner.

O.G.S.

BOOK RECEIVED

Radiosondages du gradient de potentiel et de la conductibilité électrique de l'air. By J. Lugeon and M. Bohnenblust. (Reprinted from *Annales de la Station centrale suisse de Météorologie*, 1956). 12 in. × 8½ in., pp. 14, *illus.*

WEATHER OF APRIL 1958

Northern Hemisphere

In most regions of the Northern Hemisphere the mean-pressure chart closely resembled the normal for the month, although from the point of view of synoptic types the month was more than usually heterogeneous.

The Icelandic low was near its usual position and slightly deeper than usual. Mean pressures were below normal over Greenland and Iceland but the anomalies did not exceed 5 millibars. The Azores high was also centred near its normal position. It was slightly more intense than normal and had a well-marked north-eastward extension towards the British Isles. This feature, in conjunction with a westward displacement of the Siberian anticyclone to a position over the Urals, gave positive pressure anomalies everywhere in Europe, the maximum values being +7 millibars over Ireland and +6 millibars over northern Scandinavia.

Neither the polar anticyclone nor the North Pacific high showed any significant departure from normal. The Aleutian low, however, was about 8 millibars deeper than usual and an associated area of negative pressure anomaly with a central value of −10 millibars occurred in the extreme north of the Pacific.

A larger easterly component than usual in the mean surface flow resulted in surface temperatures below normal over all Europe except in western and northern districts of the British Isles and in southern Spain. Anomalies of −3°C. were reported at a number of stations in Italy, eastern Germany and Poland, but elsewhere temperatures were within 2°C. of normal. Temperatures were also below normal in Northern Siberia and the Canadian Arctic, anomalies reaching −5°C. in both these regions. Positive temperature anomalies of +3°C. occurred in Spitsbergen, Alaska, Ontario, the Sudan, Iraq and Pakistan.

The rainfall distribution over Europe was very irregular, amounts being generally below normal in Britian, the Low Countries and Spain, but up to twice the normal in the Balkans, Italy, and parts of Norway. In northern Russia, precipitation amounts reached four times the normal in places, although totals were only of the order of 40 millimetres. There were some unusually large totals for April in eastern coastal districts of the United States of America due largely to one or two particularly vigorous depressions which moved north-east from the Caribbean. Some stations in north Florida had over four times the average rainfall for the month.

WEATHER OF MAY 1958

Great Britain and Northern Ireland

May was a cool and very unsettled month during which an almost uninterrupted sequence of depressions from the Atlantic passed over or near the British Isles. On most days a front lay over some part of the country, and rainfall during the month was above average practically everywhere.

The month opened with sunny warm weather, an anticyclone being centred over the North Sea; there was over 12 hours' sunshine at most places on the 1st and afternoon temperatures exceeded 70°F. over much of southern and central England. The following day was warmer still over the greater part of England and Wales—80°F. was reached at Farnham—but over Scotland and Northern Ireland temperatures fell about 10°F. during the day with the onset of cool northerly winds. A frontal zone became established roughly east–west across the country, with cold air to the north and warm air to the south, and persisted for about a week. The periods 5th–10th, 14th–15th, 18th–19th and 22nd–29th were rather wet and marked by fairly vigorous cyclonic activity. During the first period small depressions moved north-eastward across the British Isles on a progressively more southerly track giving widespread rain, the largest amounts falling in Wales, northern England and western Scotland; Stornoway had over 1½ inches on the 7th. The night of the 7th–8th was unusually mild especially in south-eastern England, where temperatures were in the upper fifties. After a few days of fairer weather, active depressions moved across southern England on both the 14th and 15th bringing gale force winds and heavy rain locally; many places in south-east England recorded more than ½ inch of rain in 12 hours on the 15th. A depression, which developed in mid-Atlantic, deepened as it moved north-east toward the British Isles skirting the coast of Scotland during the night of the 18th–19th and bringing considerable rain to Northern Ireland and western Scotland; associated warm air lifted temperatures in southern England, which had been below average for more than a week, into the middle sixties. There were showers and bright periods in the mainly westerly winds during the next few days. On the night of the 22nd–23rd a depression deepened off the mouth of the Bristol Channel subsequently moving northward; it was situated over the Irish Sea for most of the 23rd and reached north-west Scotland about noon on the 25th; its passage was accompanied by substantial rainfall with outbreaks of thunder over western districts of England and Wales and over much of Scotland. From the 25th to the end of the month weather over the British Isles was weakly cyclonic and rather cool with rain or showers and scattered thunderstorms. Small thundery depressions moved northwards across south-east England on the 29th giving prolonged rain in places.

The month was persistently cool apart from the first two days though there was little air frost in England and Wales. Sunshine was about average. Apart from May 1955 it was the wettest May for 16 years over England and Wales where there was 133 per cent of the 1916–50 average rainfall. Scotland and Northern Ireland had 127 and 111 per cent of the average respectively. Less than the average occurred over the greater part of the Thames Valley, Somerset, the west and north Midlands of England, in Peebleshire, the Lothians, in south-west Scotland and in Antrim, Northern Ireland. More than twice the average was recorded in the Forest of Bowland and in Ross and Cromarty.

Generally the weather of May has been kind to most farmers and growers. Apart from some reports of gale damage to early potatoes and fruit blossom about mid-month in the south-west, most areas state that vegetables are growing steadily and seeds germinating well. Strawberries and apples show good prospects but plum and pear sets are thin in several districts.

WEATHER OF JUNE 1958

The general character of the weather is shown by the following provisional figures:—

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean†	Percentage of average*	No. of days difference from average*	Percentage of average†
	°F.	°F.	°F.	%		%
England and Wales ...	78	33	—1·1	200	+6	70
Scotland	78	28	—0·2	103	—1	76
Northern Ireland ...	69	38	—0·9	195	+5	67

* 1916-1950 † 1921-1950

RAINFALL OF JUNE 1958

Great Britain and Northern Ireland

County	Station	In.	*Per cent of Av.	County	Station	In.	*Per cent of Av.
London	Camden Square ...	5·11	281	*Carm.*	Pontcrynfe	3·87	123
Kent	Dover	3·59	223	*Pemb.*	Maenclochog, Dolwen Br.	5·14	149
,,	Edenbridge, Falconhurst	4·88	271	*Radnor*	Llandrindod Wells ...	3·67	153
Sussex	Compton, Compton Ho.	3·37	164	*Mont.*	Lake Vyrnwy	4·53	124
,,	Worthing, Beach Ho. Pk.	2·78	182	*Mer.*	Blaenau Festiniog ...	6·73	74
Hants	St. Catherine's L'thouse	3·38	245	,,	Aberdovey	4·92	161
,,	Southampton, East Pk.	3·44	198	*Carn.*	Llandudno	3·77	211
,,	South Farnborough ...	2·98	183	*Angl.*	Llanerchymedd ...	5·08	212
Herts.	Harpenden, Rothamsted	4·57	267	*I. Man*	Douglas, Borough Cem.	3·83	137
Bucks.	Slough, Upton ...	4·16	254	*Wigtown*	Newtown Stewart ...	3·80	143
Oxford	Oxford, Radcliffe ...	3·31	196	*Dumf.*	Dumfries, Crichton R.I.	3·68	139
N'hants.	Wellingboro' Swanspool	5·87	365	,,	Eskdalemuir Obsy. ...	3·73	94
Essex	Southend W.W. ...	5·07	387	*Roxb.*	Crailing...	2·73	139
Suffolk	Ipswich, Belstead Hall	4·78	308	*Peebles*	Stobo Castle	3·92	163
,,	Lowestoft Sec. School	3·21	201	*Berwick*	Marchmont House ...	3·94	195
,,	Bury St. Ed., Westley H.	4·08	240	*E. Loth.*	N. Berwick	2·51	129
Norfolk	Sandringham Ho. Gdns.	2·54	129	*Midl'n.*	Edinburgh, Blackf'd H.	3·30	176
Dorset	Creech Grange... ...	2·95	160	*Lanark*	Hamilton W.W., T'nhill	3·18	135
,,	Beaminster, East St. ...	3·79	192	*Ayr*	Prestwick	2·68	117
Devon	Teignmouth, Den Gdns.	2·96	177	,,	Glen Afton, Ayr. San ...	3·76	120
,,	Ilfracombe	3·21	167	*Renfrew*	Greenock, Prospect Hill	3·49	104
,,	Princetown	6·27	138	*Bute*	Rothesay, Ardencraig...	...	...
Cornwall	Bude	3·82	213	*Argyll*	Morven, Drimnin ...	...	...
,,	Penzance	3·75	191	,,	Ardrishaig, Canal Office	3·22	79
,,	St. Austell	4·48	193	,,	Inveraray Castle ...	2·81	54
,,	Scilly, St. Mary ...	2·89	166	,,	Islay, Eallabus ...	3·41	114
Somerset	Bath	5·76	325	,,	Tiree	3·29	117
,,	Taunton	2·96	177	*Kinross*	Lock Leven Sluice ...	3·48	149
Glos.	Cirencester	3·90	187	*Fife*	Leuchars Airfield ...	2·37	139
Salop	Church Stretton ...	4·42	203	*Perth*	Loch Dhu	3·89	92
,,	Shrewsbury, Monkmore	4·58	265	,,	Crieff, Strathearn Hyd.	3·90	153
Worcs.	Worcester, Red Hill ...	3·53	235	,,	Pitlochry, Fincastle	2·84	177
Warwick	Birmingham, Edgbaston	4·23	223	*Angus*	Montrose Hospital ...	1·57	87
Leics.	Thornton Reservoir ...	3·43	190	*Aberd.*	Braemar	3·15	168
Lincs.	Cranwell Airfield ...	4·33	272	,,	Dyce, Craibstone ...	1·55	76
,,	Skegness, Marine Gdns.	2·56	168	,,	New Deer School House	1·48	66
Notts.	Mansfield, Carr Bank...	5·03	305	*Moray*	Gordon Castle	2·07	92
Derby	Buxton, Terrace Slopes	7·01	221	*Inverness*	Loch Ness, Garthbeg ...	1·50	60
Ches.	Bidston Observatory ...	4·69	237	,,	Fort William	2·11	46
,,	Manchester, Airport ...	5·41	231	,,	Skye, Duntulm... ...	1·63	49
Lancs.	Stonyhurst College ...	4·61	151	,,	Benbecula	2·25	77
,,	Squires Gate	3·53	160	R. & C.	Fearn, Geanies ...	1·87	104
Yorks.	Wakefield, Clarence Pk.	3·75	230	,,	Inverbroom, Glackour...	2·09	63
,,	Hull, Pearson Park ...	3·78	220	,,	Loch Duich, Ratagan...	2·37	49
,,	Felixkirk, Mt. St. John...	2·79	132	,,	Achnashellach	2·64	53
,,	York Museum	3·24	175	*Suth.*	Stornoway	1·53	60
,,	Scarborough	3·69	217	*Caith.*	Lairg, Crask	...	...
,,	Middlesbrough... ...	3·01	171	,,	Wick Airfield	·91	45
,,	Baldersdale, Hury Res.	3·56	173	*Shetland*	Lerwick Observatory ...	·66	31
Nor'l'd	Newcastle, Leazes Pk....	2·58	130	*Ferm.*	Belleek	4·91	144
,,	Bellingham, High Green	3·07	140	*Armagh*	Armagh Observatory ...	5·41	224
,,	Lilburn Tower Gdns ...	3·05	153	*Down*	Seaforde	7·28	290
Cumb.	Geltsdale	2·45	91	*Antrim*	Aldergrove Airfield ...	4·65	207
,,	Keswick, High Hill ...	3·98	120	,,	Ballymena, Harryville...	3·54	125
,,	Ravenglass, The Grove	4·70	171	*L'derry*	Garvagh, Moneydig ...	4·28	157
Mon.	A'gavenney, Plâs Derwen	3·33	157	,,	Londonderry, Creggan	5·89	181
Glam.	Cardiff, Penylan ...	3·12	137	*Tyrone*	Omagh, Edenfel ...	4·90	176

* 1916–1950

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