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DETERIORATION OF VISIBILITY IN RADIATION FOG

By E. EVANS, M.Sc., C. J. M. AANANSEN, M.Sc., and T. E. WILLIAMS

This statistical investigation was undertaken to examine how well founded is the impression, which is shared by many forecasters, that when radiation fog forms at inland stations the visibility passes quickly through the intermediate ranges and falls to a low value. And to see, at the same time, whether such behaviour of the visibility, if true, is related to the ambient temperature.

Sites and observations.—Hourly observations for the inclusive periods shown were examined for the following airfields which are not adjacent to any large town, and are thus largely unaffected by smoke, and which are located in three well-separated areas of the country:

Mildenhall, Suffolk	(30 feet above m.s.l.)	January, 1950–December, 1954
Scampton, Lincolnshire	(195 feet above m.s.l.)	September, 1953–May, 1955
Waddington, Lincolnshire	(235 feet above m.s.l.)	June, 1955–August, 1955
Shawbury, Shropshire	(248 feet above m.s.l.)	January, 1950–December, 1954

Results.—First, the frequency distribution among the 200-yard ranges 0–200, 2–400, 4–600, 6–800, 800–1,000 and 1,000–1,200 yards, was determined for (i) all hours and (ii) night-time, for the occasions when a visibility of 1,200 yards or less was reported under all conditions (radiation and non-radiation) at Mildenhall and Shawbury; and then a similar frequency distribution for only radiation nights for the four stations. The results in Table I were obtained, the values for Scampton and Waddington being combined.

These figures, which show such a uniformly high percentage for visibilities in the 0–200-yard range and a significant minimum in the 6–800-yard range under radiation conditions (for visibilities below 1,000 yards), make a prima facie case for the broad contention that when fog, particularly radiation fog, forms, the visibility falls rapidly through the intermediate ranges to a rather low value.

But the majority of radiation fogs form in the winter, when the cooling period still remaining after the fog has first formed is often sufficiently long for the visibility to ultimately reach a low value and to stay so for two or more hours—a cumulative process which gives bias to the frequency distribution in favour of a low visibility.

TABLE I—PERCENTAGE FREQUENCY DISTRIBUTION OF VISIBILITY IN DIFFERENT RANGES

Airfield	Visibility range 0–200	2–400	4–600	6–800	800–1,000	1,000–1,200 *yards*
	Percentage frequency distribution					
	All hours (all conditions)					
Mildenhall (2,363 occasions)	26·5	14·6	14·1	10·5	17·4	16·9
Shawbury (2,359 occasions)	31·1	9·1	11·9	11·7	18·1	18·0
	Night-time (all conditions)					
Mildenhall (1,522 occasions)	26·7	15·2	14·2	11·0	17·3	15·6
Shawbury (1437 occasions)	32·2	9·4	13·2	12·2	18·2	14·8
	Radiation nights					
Mildenhall (677 occasions)	38·0	16·1	10·6	6·9	14·0	14·3
Shawbury (964 occasions)	31·3	12·6	14·4	11·9	19·9	9·9
Scampton/Waddington (492 occasions)	33·1	19·3	13·6	11·2	13·0	9·8

To determine the true reality of the effect, therefore, the investigation was carried a stage further by examining how visibility in radiation fog varies progressively from hour to hour whilst radiation continues. For this, examination was made of the hourly observations from the first (hourly) observation after sunset until the last before sunrise on radiation nights at Mildenhall for the inclusive months and years January–April and September–December, 1950–55; and the examination was restricted to those occasions when a deterioration of the visibility to 1,200 yards or less occurred within this period. The following results were obtained, "1st Hour" meaning that at which a visibility of 1,200 yards or less first occurred, and the 2nd, 3rd . . . . hours being those subsequent to this:

TABLE II—PERCENTAGE FREQUENCY DISTRIBUTION OF HOURLY OBSERVATIONS OF VISIBILITY AT MILDENHALL

Visibility range	Hour 1st	2nd	3rd	4th	5th	6th	7th
	Percentage frequency distribution						
1,000–1,200 *yards*	23	12	6	7	9	8	7
800–1,000	33	24	24	14	3	4	5
600– 800	11	13	12	11	16	11	5
400– 600	11	8	11	11	3	6	7
200– 400	10	13	9	13	16	17	15
0– 200	11	30	38	43	53	54	60
No. of occasions (Visibility<1,200 yds.)	154	115	88	70	57	52	48

Whilst this table shows a marked hourly increase in the percentage of visibility below 200 yards (the hourly variation even for the adjacent 200–400-yard range is small and irregular), it also shows very significantly the absence of any well marked maximum in any of the intermediate ranges 2–400, 4–600 and 6–800 yards at any hour: when the visibility deteriorates further after the initial formation of radiation fog it tends to pass rapidly through the intermediate bands and to fall quickly to a low value.

The persistence of a high value in the 800–1,000-yard range for the first few hours suggests some reluctance on the part of the visibility to deteriorate further after the initial formation of radiation fog. But when further deterioration does take place, then it is likely to be serious.

Relation to temperature.—The statistics extracted did not exhibit, until at least after the 3rd hour, any connexion between the tendency for radiation fog to thicken rather quickly and the ambient temperature.

ABNORMALLY LOW HUMIDITY IN SCOTLAND

By R. C. SMITH, Ph.D.

Frequency of occurrences.—Since 1900 there have been recorded at least seven occasions when the humidity in the British Isles fell below 20 per cent. These have been listed by, among others, Bilham[1,2], Hawke[3,4] and Needham[5]. The lowest on record are shown to be 9·5 per cent. at Parkstone, Dorset in 1901 and 10 per cent. at Kew on the afternoon of April 15, 1942. The synoptic situations associated with these were of the type–large high over Scandinavia with the air having a long land track and presumably subsiding as well. One has to be careful to make comparisons with stations near sea level as it would be expected that at the mountain stations a larger number of exceptionally low humidities would be reported coinciding with the larger number of subsidence inversions getting below the level of the station.

On the afternoon of June 10, 1956 the exceptionally low humidity of 18 per cent was recorded at Kinloss in Scotland. There were also reports from other stations in the area of very dry air during the same day. As occasions of such dry air reaching the surface are rare, the circumstances surrounding this phenomenon are examined more closely.

Synoptic situation.—On June 7 a depression of 1000 mb. moved south-east across the Southern Highlands into the North Sea and brought deep cold air into Scotland behind it. A sharp ridge ahead of a warm front over the Atlantic, moved slowly east on the 8th. On the 0001 G.M.T. surface chart of the 9th, a separate high centre of 1029 mb. was drawn south of the Faroes. This moved slowly east-north-east and intensified. A ridge extended south-south-west over Scotland from it and, by 0001 G.M.T. on the 10th, a separate centre of 1029 mb. was positioned east of Scotland with the main high over north Norway; central pressure was 1033 mb. By midday on the 10th the warm front was lying along a line Western Isles–60°N., 5°W.–65°N., 1°E.

Upper air situation.—On examining the tephigrams of the previous few days, it became fairly obvious that the air had originated from the region of the tropopause. The radio-sonde ascents from Lerwick, Aldergrove, Leuchars and Stornoway at 1400 G.M.T. on June 7 showed a fairly typical polar maritime air mass over the region. The tropopause at Lerwick was at 24,000 ft.

The Lerwick ascents were chosen for closer examination as they seemed to typify best the main subsidence area. Fig. 1 shows sections of these ascents from 1400 G.M.T. on June 7 to 1400 G.M.T. on June 10. To avoid confusion, only the section of each temperature curve between the 20°C. and 30°C. potential temperature lines was plotted together with the corresponding humidity readings.

The upper winds for Lerwick for the same period have been plotted in Table I, and the sections, corresponding to the parcel being dealt with on the tephigram, marked off. As can be seen by inspection, after June 7 the winds

TABLE I—UPPER WINDS FOR LERWICK JUNE 7–10, 1956

The values between the horizontal lines correspond to the parcel being followed on the tephigram for that time.

	June 7th		June 8th				June 9th				June 10th			
	Greenwich mean time													
mb.	1400	2000	0200	0800	1400	2000	0200	0800	1400	2000	0200	0800	1400	2000
900	190 20	190 16	120 07	010 13	250 17	360 16	030 16	030 06	300 05	240 06	220 08	220 07	200 06	180 06
850	190 20	180 16	120 08	020 09	350 13	350 24	010 12	040 05	220 05	230 06	220 10	220 11	200 08	180 07
750	180 18	190 19	210 06	030 07	320 11	350 12	330 06	040 04	170 06	210 07	190 05	200 09	200 14	180 13
700	180 18	200 18	270 03	040 06	300 10	340 09	340 06	030 04	170 08	180 06	180 03	190 09	200 15	190 17
600	190 21	200 22	240 07	220 07	260 07	340 16	360 07	030 03	170 09	180 05	150 06	200 12	190 15	190 14
500	190 19	230 25	210 10	210 16	250 14	350 25	350 09	160 04	230 06	220 07	200 06	190 11	200 15	200 15
400	190 24	220 19	200 11	200 53	360 32	340 28	350 10	190 05	240 16	240 07	030 03	130 15	170 11	200 18

Wind direction in degrees from true north. Wind speed in knots were light and variable throughout the layer thus increasing confidence in the selection of the one station to represent the situation.

Fig. 1 shows what might be a typical example of subsiding air in the atmosphere. The temperatures in each successive sounding move down the dry adiabatics regularly with the exception of the sounding for 0200 G.M.T. on June 9. The dew points move down the water-content lines with the exception of the sounding for 1400 G.M.T. on June 9 when the air is relatively more moist.

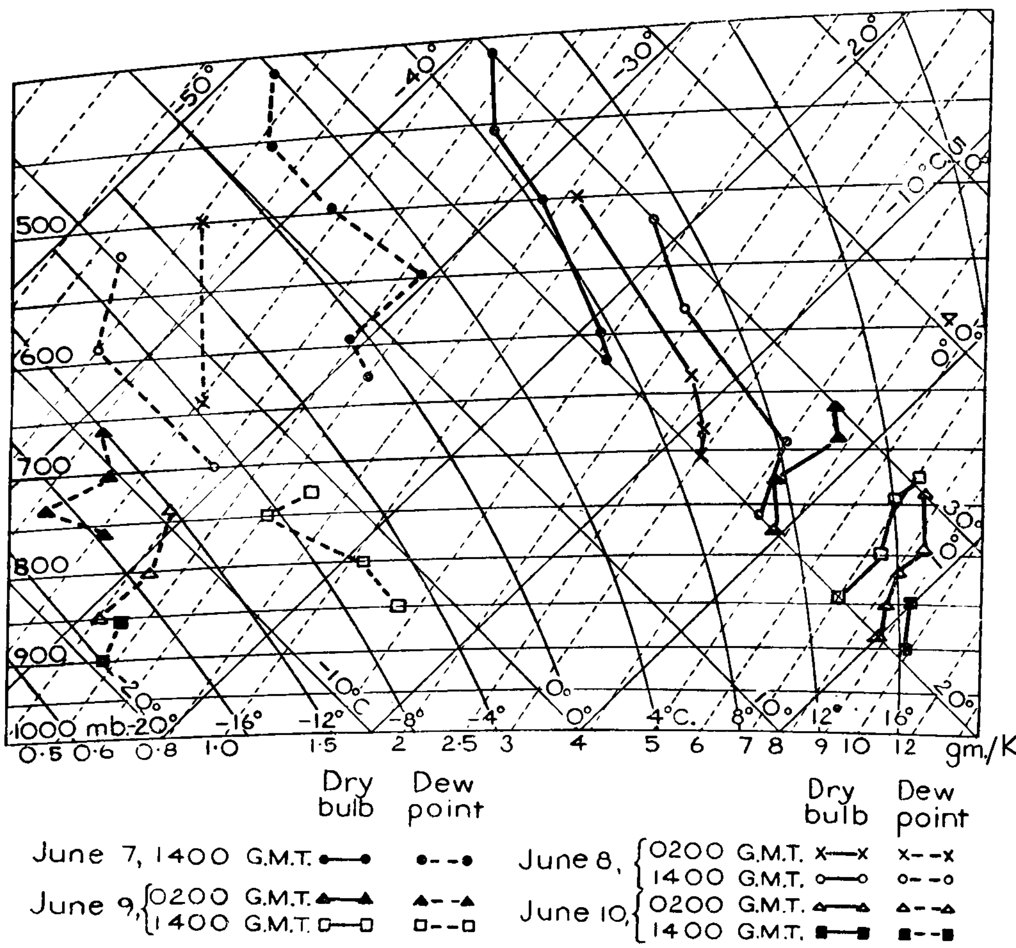

FIG. 1—SECTIONS OF TEPHIGRAMS FOR LERWICK JUNE 7 TO JUNE 10, 1956

This last feature can be explained as follows:—during the morning and afternoon of June 9 the wind direction at Lerwick, at the appropriate level, changed by approximately 180° to a direction of 230° as the axis of the ridge passed through the station. This direction introduced relatively moister air, as is indicated by the Stornoway ascent of 1400 G.M.T., until the new high centre was formed off east Scotland. This fed in the drier air from the east although maintaining a south-westerly air-stream at Lerwick.

The soundings at Leuchars over the period also showed signs of the dry air although not so consistently as those at Lerwick. In particular, at 1400 G.M.T.

on June 10, there was a dew-point of −18°C. at the 970-mb. level. Above the 800-mb. level the air was considerably moister.

Surface reports.—

(i) Kinloss reported a fall in humidity on the afternoon of June 10 to a minimum of 18 per cent at 1600 G.M.T. The dew-point fell from 6·5°C. at 1400 G.M.T. to −5·8°C. at 1600 G.M.T. Wind veered from 010°/11kt. at 1400 G.M.T. to 080°/12kt. at 1600 G.M.T.

(ii) At Dalcross, near Inverness, a minimum humidity of 34 per cent occurred just after 1400 G.M.T. This was taken from a hygrograph trace as the station was not manned during the week-end.

(iii) At Wick, 119 ft. above sea level, there was a rapid fall of humidity at 1230 G.M.T. to 72 per cent despite the wind blowing directly from the sea at 130°.

(iv) Green[6] records that between 1030 and 1130 G.M.T. on June 10 the humidity fell to 8 per cent at a height of 1,000 ft. in the Cairngorm Nature Reserve.

As a value for comparison, the humidity at the 900-mb. level for the sounding at 1400 G.M.T. on June 10 is 5 per cent.

Conclusion.—It appears that the dry air, which eventually reached the surface in places, originated near the tropopause and descended almost *in situ*. From the Lerwick soundings the vertical velocity is roughly 3 ft. per min. for the first falling to 2 ft. per min. on the last day. Using the observations (i) and (iv), the vertical velocity of the air was also 3 ft. per min.

Another interesting associated feature at Kinloss was that, after the time of minimum humidity had been passed, the inversion still persisted over the Moray Firth giving an inverted mirage of the mountains at the far side as shown in Fig. 2. The fact that the dry air ever arrived at the surface at Kinloss is probably connected with the local sea-breeze circulation as is indicated by the sudden wind veer accompanying the humidity change.

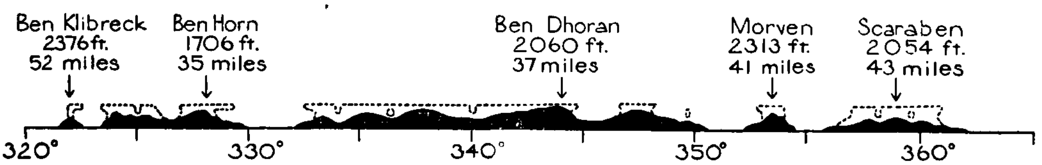

FIG. 2—MIRAGE AT KINLOSS, 2045 HR. JUNE 10, 1956

Heights of mountains and distances away from the mountains are given underneath their names.

By late evening on the 10th the dry air over Scotland had been replaced by moister air from the south, although a shallow layer of the dry air was still apparent on the morning ascent at Lerwick on June 11.

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THE OCCURRENCE OF VERY HIGH SURFACE TEMPERATURES

By H. H. LAMB, M.A.

It is reasonable to suppose that, as a general principle, the occurrence of outstanding or extreme values of any meteorological element anywhere requires the operation of several favourable circumstances, the effects of which are superposed. Absolute extremes may require the conjunction of all possible favourable influences, so far as these are all compatible.

Outstandingly high surface temperatures are favoured by

(i) Strong heating of the surface, most effective on dry desert sand or bare rock, when the sun is high and when the atmosphere is specially clear.

(ii) Long sojourn or long passage of the air over the warmest surface available.

(iii) Subsidence, which inhibits both vertical convection and local circulations, such as sea breezes, that have a three-dimensional development.

(iv) Föhn effect or passage of the air stream over mountains, most effective when condensation and rainfall produced during ascent result in latent heat of condensation being stirred into the air. (The word stirred is appropriate because the air parcels receiving the liberated heat must be dispersed through many layers of the atmosphere in the overturning which occurs after the crest is passed.) Föhn effect also helps to intensify the insolation received at places to the leeward, because rainfall during ascent washes suspended impurities out of the air, thereby tending to produce ideal transparency of the atmosphere after crossing the mountains.

(v) Advection from regions where the air has already been heated.

Reasoning from this basis, the writer hazarded the opinion some time ago that all five effects listed above might have played a part in producing the world's highest temperatures so far recorded near the fringe of the deserts of north Africa and south-western United States of America. It now seems possible to supply a little corroborative evidence.

Requirements (i) and (ii) above are obvious enough to need no justification. They are expressed by the occurrence of the highest temperatures over deserts and by the fact, which can be asserted on the basis of a sufficient network of observing stations for sampling the Sahara, that the highest individual values in north Africa, though not the highest average temperature, occur towards the leeward coast, i.e. near the end of the run of the air stream over the heated desert.

The following notes serve to illustrate the manner in which the less obvious, in some cases surprising, items (iii), (iv) and (v) seem to come into the picture.

The United States Weather Bureau's "Historical Daily Weather Maps of the Northern Hemisphere, 1899–1939", the *Tägliche Synoptische Wetterkarten für den*

Nordatlantischen Ozean und die anliegender Teile der Kontinente of the Danish Meteorological Institute and Deutsche Seewarte, 1880–1912, the weather maps in the *Daily Weather Reports*, London, and observing stations' data in *Réseau Mondial* and in various countries' daily weather reports were briefly examined to discover the synoptic circumstances in which the highest-reported surface air temperatures in the world, in Europe and in Britain occurred. Additionally the highest temperatures in the 20-yr. period 1919–38 at Cairo and Malta were similarly examined. The results are listed in note form below.—

(i) The absolute extreme for the world accepted in the "Meteorological Glossary" is 57·7°C. (136°F.) at Azizia, Tripolitania on September 13, 1922. The "Historical Daily Weather Maps" leave much room for alternative explanations of the situation over the Sahara about this time, being unsupported by plotted observational data south of the coastal region. The maps are drawn with pressure gradients for westerly winds in the north and easterly winds in the south of the desert; but a cold front was advancing east from Algeria, actually passing Azizia, 32°32′N., 13°01′E., either late on the 13th or early on the 14th, and advection of warm air from the Saharan interior with southerly and south-westerly winds was in fact established some distance ahead of the cold front. Tripoli had strong southerly winds for two successive days before the front passed. No reports of observations made at stations in the interior could be found, but by chance a British expedition to the Sahara was operating at the time in the mountains north of Agadèz in the northern part of the French Niger territory. These mountains are more or less surrounded by desert, but themselves experience from 10 to over 30 days with rain in the average year. The expedition reported heavy, sometimes torrential, rain at Auderas, 17°N., 8°E., and north of there for many hours on September 8 and 9, and rivers in high flood. No noteworthy rain fell for some days before or afterwards. The rainfall on the 8th and 9th fell from evidently extensive cloud travelling with an easterly wind. The air in which this rainfall occurred could have reached Tripolitania three to five days later after following an anticyclonically curved path of some 1,500 miles: this path is the simplest assumption for the origin of the southerly surface winds observed at Tripoli and is certainly the likeliest course for the air moving in the middle and upper troposphere around the warm area over the central desert. Warmth derived from the latent heat of condensation of the moisture which fell near Auderas was almost certainly present, at least in some of the upper levels, over Tripolitania on September 13, 1922. The hot wind of that date may in this sense be regarded as a föhn wind.

Maurice Bérenger has described a case in which moist air from the equatorial Atlantic reached the central Sahara, missing the southern mountains[1]. A Saharan depression, with a centre of 998 mb. near 30°N., 0°E., drew in a tongue of equatorial air from the south-south-west "with high temperature, great humidity and pronounced convective instability" between March 13 and 15, 1953. Abundant rain fell in the Algerian part of the Sahara in amounts up to 20 mm. in 24 hr. There were thunderstorms and blowing sand, both in the Sahara and on the north African coast, as the depression developed. It is described as rare for the equatorial air mass to reach the north coast; by implication it is less rare in the interior of the Sahara and some föhn effect over the southern mountains must be commoner than intrusion of the moist air mass itself. The cases discussed in these notes, in (i) and (vii), did not, however, involve the equatorial air mass from the Gulf of Guinea.

(ii) 56·6°C. (134°F.) was reported in Death Valley, California (37°N., 117°W.) on July 10, 1913, this being the second highest reading claimed anywhere in the world. Authenticity has been officially accepted in this and the Azizia case only after some discussion, but there is no doubt that both were extreme days. The station at Greenland Ranch, Death Valley, is 178 ft. below sea level, surrounded by deserts some thousands of feet above sea level. On July 10, 1913, a cold occlusion was passing east across the Rockies in 35°–50°N. There was anticylonic curvature in the air streams on both sides of the front and clear skies, probably with subsidence, over the deserts. It was blowing very hard on the day in question in Death Valley, the hot wind must inevitably have had its temperature further raised by adiabatic compression in the abrupt descent from the surrounding highlands.

(iii) 50·5°C. (123°F.) at Seville, Spain on August 8, 1881, is believed to be the highest temperature ever reported by a European station. 50·0°C. was also reported at Seville on July 12, 1897. In both cases it is probable that the very high temperatures occurred in air which had come from the Sahara, crossing the Atlas mountains one to two days previously between 0° and 10°E. The temperatures reported at Seville, after the air had crossed the mountains of southern Spain, were higher than the highest temperatures, 35° to 45°C., reported in northern Algeria. In both cases the air had been brought across the Atlas mountains by a shallow low-pressure system over Algeria with an extension to the west of Portugal. In the case of July 1897 there had been rainfall on the 10th and 11th at many stations in the Atlas mountains, up to 20 to 40 mm. in the day at Constantine and Géryville and at one place on the south side. It seems possible that föhn effect may be invoked, but the reported surface winds were rather erratic, as so often on the coasts of this part of the Mediterranean, and the pattern of high surface temperatures suggests that there may have been a steadier south-easterly wind at levels above about 5,000 ft. Anticyclonic curvature was probable at most levels over south Spain.

(iv) 38·0°C. (100·5°F). at Tonbridge, Kent on July 22, 1868, 75 ft. above sea level in a part of the Medway valley almost surrounded by hills, is accepted as the highest temperature so far recorded in England. The thermometers were 4 ft. above the ground in a ventilated north-east facing screen in a garden site with trees[2]. This was the culminating point of a remarkable summer in which, at Tonbridge, there were 66 days with maximum temperature over 80°F.; there had been 1 day over 90°F. in May and 8 in June; there were 9 in July, 5 in August and 2 in September. There was little thunder and "a great scarcity of rain"; drought affected vegetation and horticulture to an abnormal degree, cattle being given winter provender. The soil must have been so far dried over England and neighbouring parts of the continent that the southerly air stream of the 20th–22nd was being heated over a surface approximating to desert conditions. The synoptic situation during July was characterized by anticyclones covering a wide area of north-west Europe and occasionally linked with the Azores system. High-pressure centres were particularly frequent near Valentia, over the Scottish highlands, over the region south Norway–Zuyder Zee and south-east of Lyon. The last-named region was continuously in evidence from the 7th to the 23rd and became the dominant centre on the 18th and 19th. On the 20th cool north-westerly winds began to encroach over the north-western part of the British Isles and a more southerly air stream became general over the rest of the country, bringing still warmer air over England from the south. The anticyclone centre itself shifted north to the Channel for a time on the 20th and 21st. On the 22nd there was a ridge from a high-pressure centre near the Alps as far as central England and Holland; in this ridge subsidence must have been still occurring, the sky at Tonbridge being clear and the wind light, but cool, north-westerly winds were spreading further south over Britain and the cold front passed Tonbridge without rain on the 23rd. By the 24th a new anticyclone, 1035 mb., was centred over Fife and with a north-easterly air stream from the North Sea the maximum temperature at Tonbridge only reached 23°C. (73°F.), this being the coolest day for over a month.

(v) 37·8°C. (100°F.) at Greenwich on August 9, 1911 is the second highest accepted temperature reading in Britain. This occurred about 50 miles east of the cold front, orientated north–south of a depression between the Hebrides and Iceland. There was a wide area of warm air and light winds over central Europe south of an anticyclone over Scandinavia, but just ahead of the cold front still warmer air was drawn on an anticyclonically curved track from France and the Alps. Subsidence is suggested by the highest temperatures of the month at French mountain stations up to 2,500 m. above sea level. Prolonged warm weather beforehand was probably important in this case as in 1868.

(vi) Cairo's highest temperatures in the years examined were 47·5°C. on June 13, 1933 and 46·1°C. four days earlier, on June 9, 1933. These occurrences were with a fresh southerly wind, associated respectively with the warm and cold frontal troughs of a depression passing over the Balkans towards the north European plain. Temperatures at Cairo were appreciably higher than at desert stations before the air reached Cairo, but very high values spread as far as Palestine. There was some anticyclonic curvature of the air path. It is well known that Cairo's highest temperatures commonly occur early in the season with the southerly winds ahead of Khamsin depressions, i.e. ahead of tongues of cold air which have reached the Mediterranean.

(vii) In Malta the importance of both subsidence and advection is unmistakable. The island, 18 by 8 miles, is too small for sea breezes to be well developed except under favourable conditions: a subsidence inversion at any height between 900 and 600 mb. usually means that no sea breeze will occur, and, with little general wind, at the height of summer this condition is liable to give a hot, still day with temperatures well over 30°C. The highest temperatures in the 20-yr. period 1919–38 examined, in each case approximately 40°C. (104°F.), on July 12, 1919, July 7, 1931 and August 7, 1931, all occurred with a small anticyclone centred over the sea area of the Gulf of Sidra, 200–300 miles south-east of the island, which was experiencing a drift of air from Africa. In all three cases the advection from Africa was increasing on the day in question with the approach of a cold front or frontal trough from the west. Temperatures over 35°C. (95°F.) in Malta are commonly followed within a day or two by much cooler air from the north-west.

The summer of 1931 was of special interest both in Malta and in the central Sahara. Over Africa continual south-easterly winds from mid June to mid September brought very high temperatures, commonly 45° to 48°C., to places in the desert in south-eastern Algeria, downstream from the mountains of the Sahara. As we have mentioned, rainfall is not rare in the southern ranges near Agadèz. The position of the warmest patch shifted with the day-to-day changes in orientation of the wind stream, being always downstream from the mountain massifs. Temperatures in the Sahara in southern Algeria were much lower, about 35°C., on the days when a north-easterly air stream was between the Atlas and Ahaggar ranges, but rose to 40° to 45°C. in this area on those days which had northerly or north-westerly winds from across the Atlas range.

The very warm air was diverted as a south-westerly or southerly wind out into the central Mediterranean, bringing outstandingly high temperatures to Malta and Italy, each time a cold front penetrated across the Atlas mountains, notably about July 5–7, August 6–8, and September 11–13, 1931.

These notes appear to confirm the importance of the factors named at the outset and further suggest that very many of the peak temperatures, even in and near north Africa and the deserts of south-western United States of America are associated with the speeding up, and longer fetch, of warm air advection just ahead of a cold front. The writer was left with the further impression that in most, perhaps all, cases here examined the actual peak temperatures may have been very local and associated with some locally forced turbulence—for instance, in air descending some sort of declivity or merely passing over town buildings—the circumstances being such as to raise adiabatically by a degree or two the temperature of already very warm air at a slightly higher level.

The evidence of föhn effect in the central Sahara in air streams crossing the mountain ranges in the French Niger territory, the Ahaggar massif and the Atlas range, is of interest because it indicates that even in the central Sahara the maximum effect of solar heating is not simply and directly a measure of the intensity of the incoming radiation, but also depends to some extent upon the circulation patterns prevailing in the atmosphere. The same conclusion is implied by the considerable variations from haze to clear air reported over the desert.

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THE EVALUATION OF WINDS AT 200 MILLIBARS FROM CONTOUR CHARTS

By R. F. ZOBEL, B.Sc.

Introduction.—Both the upper air forecaster and the climatologist may frequently be confronted with the problem of the evaluation of upper winds from contour charts. In regions where a dense network of radar wind measurements is available the problem is much simplified, but where such does not exist, complete reliance must be placed on the contour gradient. This is also always the case when interpreting prognostic contours. It then becomes necessary to make a decision as to the method of interpretation of the contours that shall be adopted. In other words should one adopt geostrophic values as the best approximation to the actual wind, or should one attempt corrections for curvature of the contours and use what will be referred to as gradient wind?

In view of the uncertainty as to the answer to the above question (*vide*, for example Murray[1]) it was decided to carry out a careful comparison between measured winds and corresponding geostrophic and gradient winds as deduced from 200-millibar contour charts. This report describes the results of the comparison using 0200 G.M.T. observations for Crawley during the 12-month period December 1954 to November 1955. It is shown that, on the whole, the gradient wind gives the best approximation to actuality.

Technique for obtaining gradient winds.—The relationship expressing the difference between gradient wind and geostrophic wind, where the motion is balanced, is

$$V_g - V_o = \pm \frac{V_o^2}{\lambda r}, \qquad \ldots\ldots (1)$$

(*vide*, for example Petterssen[2]) where V_g and V_o are geostrophic and gradient winds respectively, λ is the Coriolis parameter and r the radius of curvature of the trajectory.

For the purpose of this trial the curvature of the trajectory was considered to be equal to that of the instantaneous contour at any point. The approximation was imperative, because charts were not available at week-ends and certain other times, so that it was not possible to determine trajectories on a regular basis. It may be expected, however, that the effect of the approximation would not be large at 200 millibars. For example, Petterssen[3] shows, in relation to the circulation patterns of strong winds aloft, that it is satisfactory to equate the curvature of the contour to that of the trajectory. This procedure also greatly reduces the amount of labour involved in making the gradient approximation, which is one of its greatest drawbacks.

If one is dealing solely with a single point, as in this instance, that is, Crawley it is not unduly laborious to solve equation (1), but where gradient approximations are required for a number of places having different latitudes, it has been found more convenient to construct tables, for day-to-day use. Gilbert[4] has produced tables based on a theoretical approach by Petterssen[5]. These tables may readily be adapted to suit the extra assumption that the curvatures of the trajectory and contour are equal. This is tantamount to considering the pressure systems as stationary, so that Gilbert's value of the speed of a pressure system (c) may be equated to zero. Gradient approximations for Crawley were actually deduced from tables constructed in this way, since they were already available. It has been ascertained that the method of correction adopted gives approximations to the gradient wind in close agreement with those derived by the use of the method due to Silvester[6], but it is considered that the use of tables is more expeditious.

It should be noted that no consideration was given throughout to unbalanced accelerational terms, since these cannot be evaluated from synoptic charts.

Accumulation of the data.—During the period December 1954 to November 1955 inclusive, the geostrophic wind over Crawley at 200 millibars was measured from contour charts for 0200 G.M.T. on 236 occasions. Corrections to gradient wind were made on 164 occasions and of those 101 were cases of cyclonic curvature whilst 63 were anticyclonic. The remaining 72 occasions were those on which the contours over the region of Crawley were regarded as straight. Entries of the necessary parameters were extracted from the charts and recorded daily. The actual wind as measured at Crawley was not plotted on the chart until the above entries had been made. Winds and 200-millibar heights were plotted at all other available stations. Contours were drawn with respect primarily to the height values, but the interpolation of lines between stations was assisted to some extent by the measured wind values. In this way the contours over the United Kingdom were drawn as accurately as possible, so that errors in geostrophic wind values should tend towards the minimum. This was considered to be the most useful procedure, since the results would then also be applicable to prognostic contours, which must be accepted as accurately portraying the anticipated wind field.

Results of the comparisons of geostrophic, gradient and actual winds.—Each day the vector differences in knots, between the actual wind and the geostrophic wind, as well as the difference between the actual wind and the gradient wind, were computed. At the end of the period of comparisons daily results were combined for the whole period, occasions of straight contours, anticyclonic and cyclonic curvatures being treated separately. Table I shows the number of occasions on which the departure from actuality attained given values.

TABLE I—NUMBER OF OCCASIONS ESTIMATED WINDS WITHIN GIVEN LIMITS OF VECTOR ERROR

Errors within given range	Cyclonic		Anticyclonic		Straight
	Geostrophic	Gradient	Geostrophic	Gradient	
kt.					
0– 5	27	43	17	24	20
6–10	23	33	18	16	29
11–15	26	12	12	10	13
16–20	9	6	4	5	6
21–25	8	3	5	7	4
26–30	4	2	4	1	0
31–35	3	1	2	0	0
36–40	0	1	1	0	0
>40	1	0	0	0	0
Total occasions	101	101	63	63	72

Frequency–error curves were computed from Table I and these curves are shown at Figure 1. It is apparent that on an over-all basis, the errors associated with the estimates of gradient winds are appreciably less than these associated with the geostrophic estimates.

It was considered to be a worth-while study to ascertain if the over-all superiority of the gradient wind applied generally, or whether this superiority was confined to winds from particular directions, to certain ranges of wind speed or to certain ranges of curvature. Consequently further analysis was undertaken for this purpose.

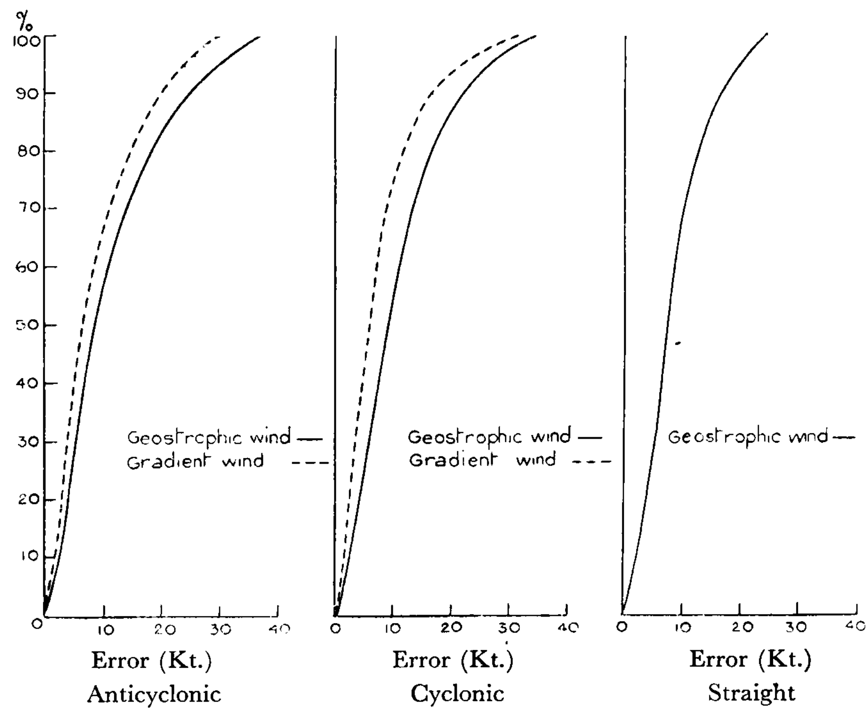


FIG. 1—FREQUENCY OF ERRORS NOT GREATER THAN GIVEN LIMIT

Relationship of geostrophic and gradient winds to radius of curvature.—The root mean square vector errors of the geostrophic and gradient winds were computed for three ranges of curvature of the contours for both cyclonic and anticyclonic occasions and these are shown in Table II.

TABLE II—ROOT MEAN SQUARE VECTOR ERRORS OF GEOSTROPHIC AND GRADIENT WINDS IN RELATION TO VARIOUS RADII OF CURVATURE OF THE CONTOURS

	Radius of curvature (nautical miles) Cyclonic				Anticyclonic				Straight contours
	≤499	500–999	1000–3000	All	≤499	500–999	1000–3000	All	
					knots				
Geostrophic	15	13	16	15	13	17	13	15	11
Gradient	10	10	13	11	12	14	11	12	

It is apparent that the over-all advantage of the gradient wind is maintained through all ranges of curvature whether cyclonic or anticyclonic and that the corrections applied are such as to reduce the vector errors associated with curved contours to the same order as for straight contours. It is also of interest to note that the values of 11 knots, 12 knots, and 11 knots shown respectively for all cyclonic, anticyclonic and straight contours are appreciably less than the value of 18 knots quoted by Murray[1] for the "apparent departure from geostrophic values on working charts" for the 200-millibar level. At the same time the corresponding values for geostrophic winds in Table II are, when combined (14 knots), also less than Murray's figure of 16 knots for "overall inherent technique errors". Although Murray's charts were replicas of working charts showing plotted wind data, it is believed that his figures were based on observations during a single spring month and that he included data from stations such as weather ships where the average wind is greater and the network less dense than at Crawley. Strict comparisons are not therefore possible.

Relationship of geostrophic and gradient winds to wind speed.—Table III shows root mean square vector errors for cyclonic, anticyclonic and straight contours for various ranges of measured (actual) wind speed.

TABLE III—ROOT MEAN SQUARE VECTOR ERRORS FOR VARIOUS RANGES OF MEASURED (ACTUAL) WIND SPEED

	Range of wind speeds (knots)					
	Cyclonic					
	0–19	20–39	40–59	60–79	80–99	⩾100
Geostrophic	10 (19)	13 (40)	18 (32)	17 (9)	... (0)	14 (1)
Gradient	9 (19)	9 (40)	13 (32)	18 (9)	... (0)	10 (1)
Straight	8 (17)	9 (18)	11 (19)	13 (11)	15 (4)	16 (3)
	Anticyclonic					
	0–19	20–39	40–59	60–79	80–99	⩾100
Geostrophic	11 (8)	9 (15)	12 (22)	16 (11)	21 (2)	30 (5)
Gradient	12 (8)	12 (15)	12 (22)	10 (11)	16 (2)	18 (5)
Straight	8 (17)	9 (18)	11 (19)	13 (11)	15 (4)	16 (3)

Number of occasions shown in brackets

Values for straight contours have been shown under both cyclonic and anticyclonic headings for comparative purposes. It is clear that the advantage of the gradient wind is fairly evenly spread through all ranges of speed, in cyclonic cases, whereas in anticyclonic cases it is confined to winds in excess of 60 knots. In such instances the advantage of the gradient wind is considerable. Although the analysis is unfortunately confined to eighteen cases of anticyclonic winds in excess of 60 knots, the effect is probably real, since the root mean square errors of these gradient winds are of the same order as for straight contours.

Relationship of geostrophic and gradient winds to wind direction.—A comparison of errors in relation to wind direction was felt to be likely to afford an indication of the effect of neglecting the movement of pressure systems. For example the trajectory of air on the north side of a moving depression may be considerably different from the instantaneous stream-line, so that errors in curvature are likely to occur and these may completely nullify the advantage of the gradient wind in certain wind directions. That this tends to be so is apparent from Table IV. For other than straight contours the values in the table have been plotted on polar diagrams in Figures 2 and 3 (facing p. 48). In constructing these diagrams values have been smoothed between directions and two obviously fortuitously low values, based on a small number of observations (north-north-east cyclonic and south-south-west anticyclonic) have been more or less disregarded. The diagrams indicate that for cyclonic curvatures the gradient wind is the better approximation for winds between south-east and north-north-east through west, whereas the geostrophic is a better approximation for winds from between south-east and north-north-east. For anticyclonic curvatures the gradient wind approximation is superior for all directions, except between east-north-east and east-south-east, where the geostrophic wind approximation is equally good. In both diagrams regions have been hatched where the geostrophic wind is apparently superior to the gradient.

TABLE IV—ROOT MEAN SQUARE VECTOR ERRORS OF GEOSTROPHIC AND GRADIENT WIND IN RELATION TO WIND DIRECTION

	Range of wind direction (degrees from north)							
	001–045	046–090	091–135	136–180	181–225	226–270	271–315	316–360
	knots							
Cyclonic								
Geostrophic ...	6 (7)	14 (9)	11 (1)	11 (2)	12 (19)	16 (25)	18 (25)	17 (13)
Gradient ...	3 (7)	15 (9)	13 (1)	9 (2)	9 (19)	9 (25)	15 (25)	14 (13)
Anticyclonic								
Geostrophic ...	13 (10)	12 (5)	... (0)	13 (1)	7 (4)	19 (10)	12 (21)	14 (12)
Gradient ...	11 (10)	12 (5)	... (0)	14 (1)	8 (4)	13 (10)	13 (21)	11 (12)
Straight								
	12 (12)	... (0)	8 (1)	14 (3)	7 (6)	10 (19)	10 (18)	12 (13)

Number of occasions shown in brackets

Detailed re-examination of the individual cyclonic occasions shows however that there were eleven occasions of winds from between 025 and 135 degrees. Of these, there were nine occasions when the gradient wind was more accurate than the geostrophic. One of the remaining two occasions was that shown under heading 091–135 degrees in Table IV. The other was an occasion when both the gradient and geostrophic winds were considerably in error (namely, 38 and 30 knots respectively). This probably indicates an unusually large error in chart drawing, so that the shaded area on Figure 2 may be largely spurious, being based on a small number of observations. This is supported by the fact that differences under discussion (Table IV, cyclonic) are not statistically significant. The inference is therefore, that in general the gradient approximation will be at least as accurate as the geostrophic for easterly winds, and appreciably better for winds from other directions, irrespective of curvature.

Summary of conclusions.—The comparisons indicate that:

(i) There is a general over-all increase of accuracy of wind estimation from contour charts at 200 millibars when the geostrophic wind is corrected to gradient wind by means of a correction for curvature of the contours.

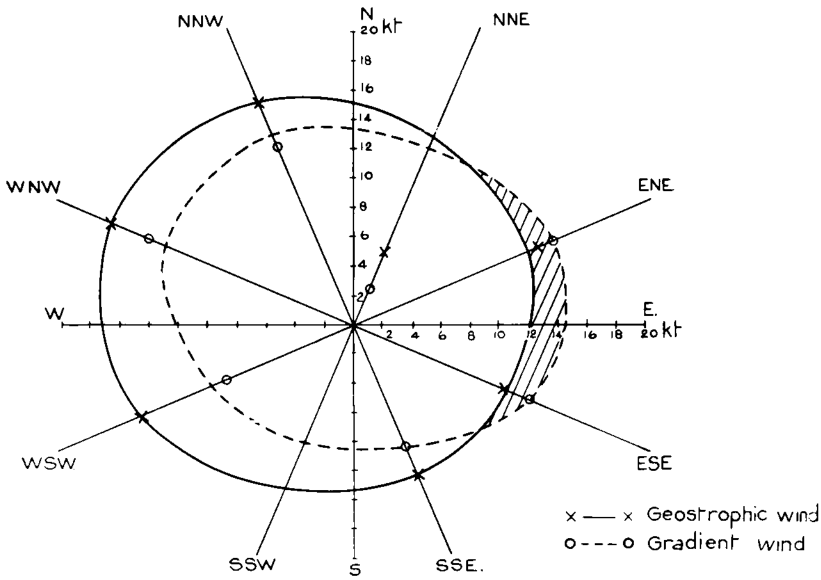
(ii) The increase of accuracy applies to both types and all degrees of curvature.

(iii) Accuracy is most markedly improved if the curvature is anticyclonic and the wind speed in excess of 60 knots.

(iv) The improvement of the gradient approximation over the geostrophic is appreciable for wind direction of either curvature between south-east and north-east through west. For other directions the accuracy of both is approximately the same.

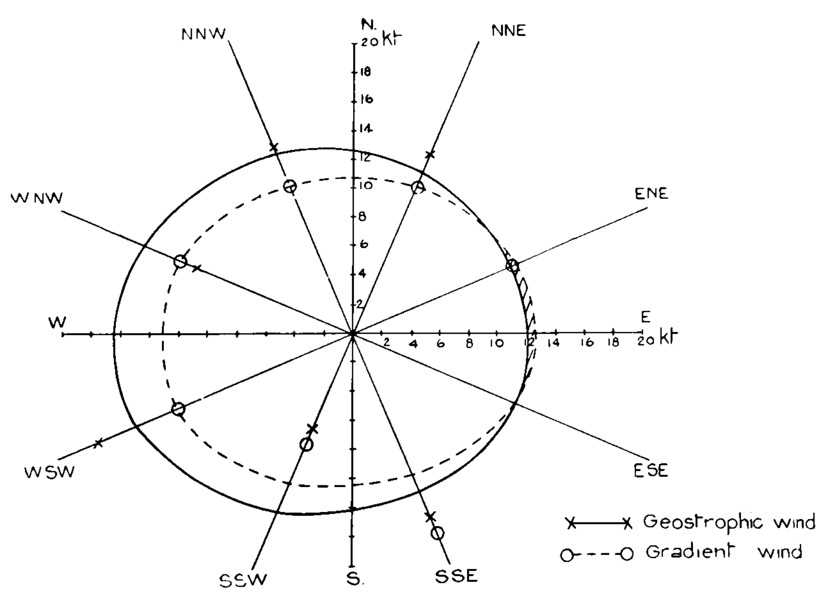
In view of the previous paragraph it is concluded that work of the highest accuracy requires that geostrophic winds derived from contour charts at 200 millibars should be corrected for the cyclostrophic term. By this means errors may be appreciably reduced.

[*To face p.* 48]



Cyclonic

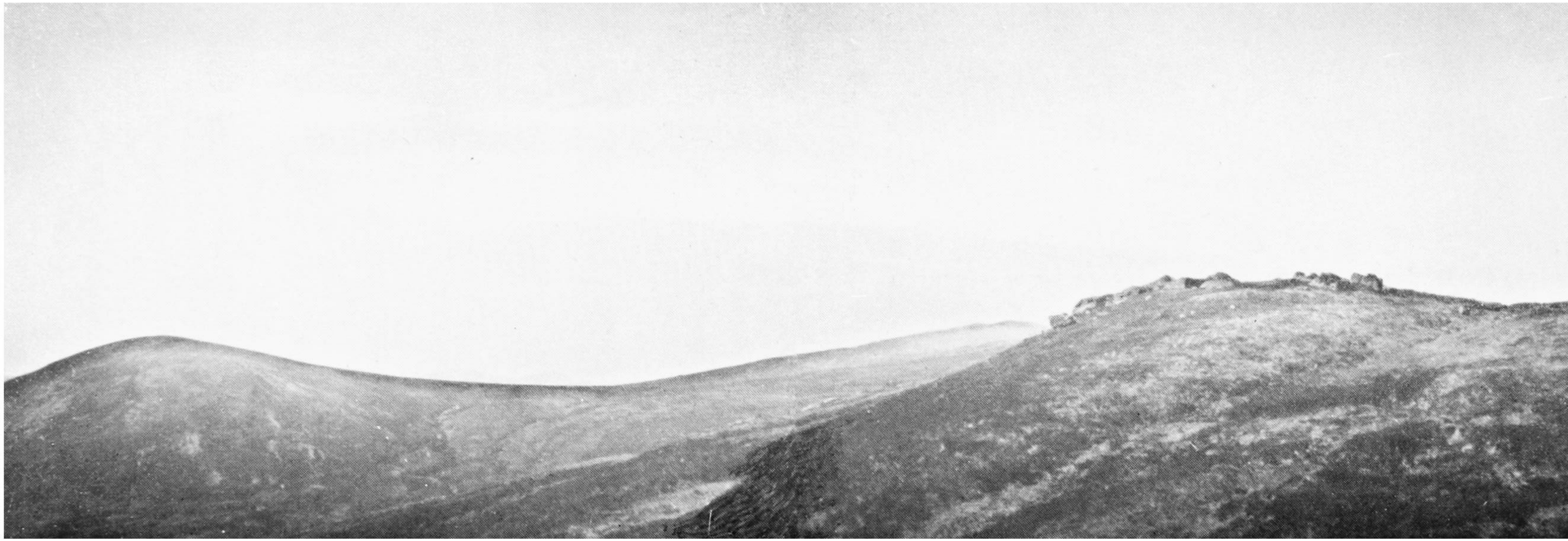
FIG. 2—ERRORS IN RELATION TO WIND DIRECTION



Anticyclonic

FIG. 3—ERRORS IN RELATION TO WIND DIRECTION

(see p. 47)



Photograph by R. Cranna

WAVE CLOUD AND VIRGA OVER GLEN AFFRIC, INVERNESS-SHIRE

The photograph was taken from Carn Loch na Gobhlaig, a hill to the north of Glen Affric, on June 1, 1955 at 1140 G.M.T. The camera was at a height of 2,000 feet and the bearing of the leading edge of cloud from the camera was south west by west. The elevation of the leading edge varied between 15° and 6°. The winds over the area at the time were of the order of 140° 30 knots.

STATIONARY STRATOCUMULUS ROLLS

We are indebted to Mr. J. Dowding of the Photographic Section at Defford, Worcestershire and Mr. H. Bird, Meterological Officer there, for a series of 96 photographs taken at 10-second intervals showing two approximately stationary cross-wind rolls of stratocumulus cloud to the west of Defford in a westerly wind. One of the photographs is reproduced above.

The photographs were taken between 1002 and 1021 G.M.T. on December 5, 1956. The surface wind was 260° 22 knots and the gradient wind 285° 35 knots. The rolls appear to be of the Helm cloud type produced by lee waves from the Welsh mountains. Conditions were favourable for the formation of lee waves as Scorer's parameter increased with height from 0·84 mi^{-1} between 1,000 and 900 millibars, to 1 mi^{-1} between 800 and 600 millibars and over 2 mi^{-1} at greater heights.

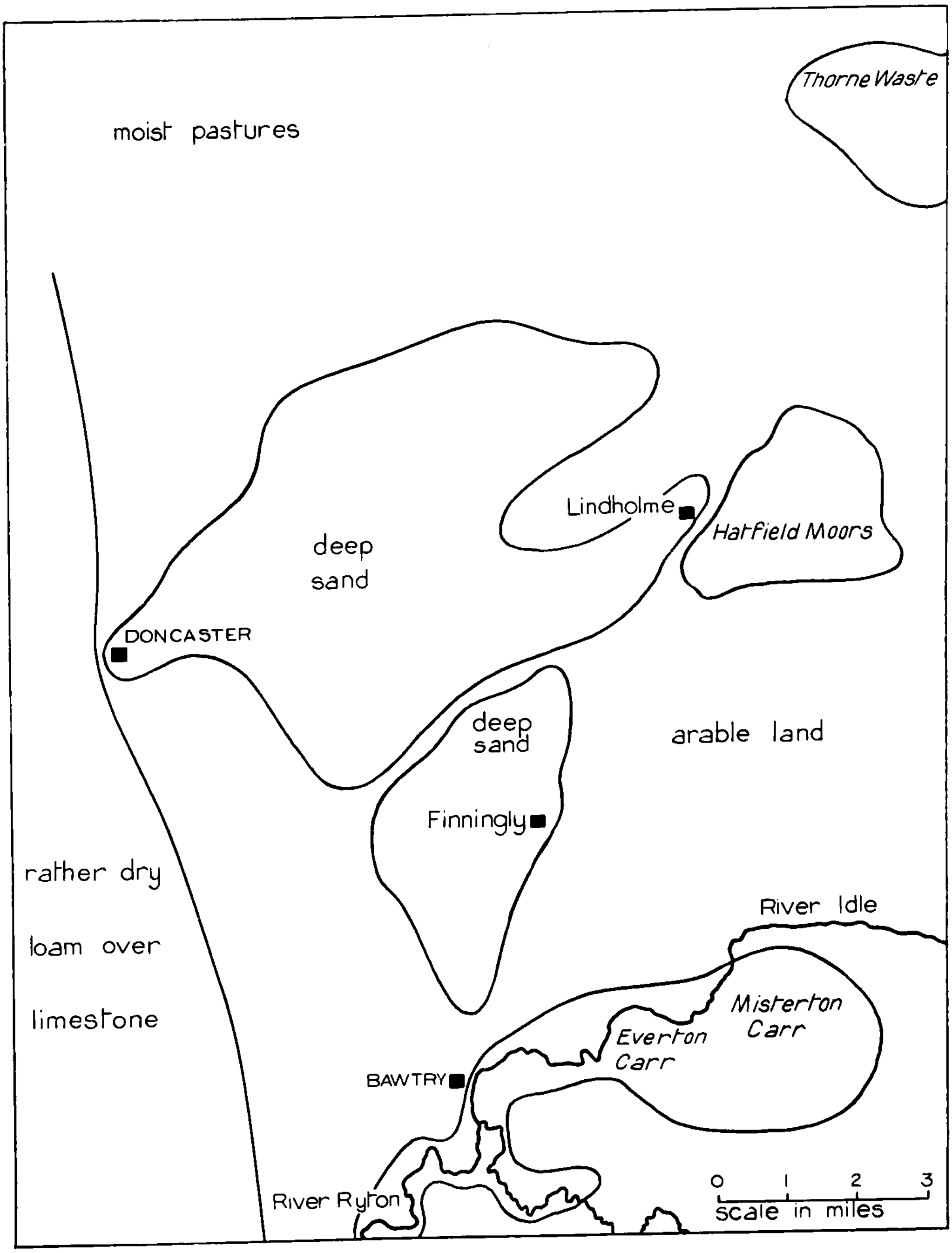


FIG. I—SOIL TYPES IN THE AREA

(see p. 49)

Acknowledgement.—The necessary correction tables were prepared by Mr. B. G. Wales-Smith. He also made many of the day-to-day wind estimates, corrections, and determinations of individual vector errors.

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LETTER TO THE EDITOR

Effect of soils on the duration of high humidity

In a recent paper[1] by L. P. Smith on the duration of high relative humidities in summer, attention was drawn to the apparently higher duration at Lindholme as compared with Finningley five miles to south-south-west; Lindholme 1029 hours, Finningley an estimated value of 589 hours. To a meteorologist stationed in the area it is hard to believe that such a difference could be associated with a diminution in the effect of the Pennines at Lindholme as compared with Finningley. Finningley is 22 miles from the Pennines and Lindholme is 1 mile further east: the dry zone behind a hill would, as Smith says, have to have sharp edges indeed to produce so great a difference.

The writer has examined the humidities recorded in the summer of 1945 when both stations kept full observations throughout the 24 hours, although only 3-hourly in the case of Lindholme. The numbers of hours during which the relative humidity was 90 per cent or above during June–September, 1945, prove to be

Lindholme	924 hours
Finningley	921 hours

(based on 3-hourly observations at both stations, trebled, as are all the statistics which follow). As the prevailing wind during the period was westerly (see Table I), it is clear that in fact the two stations benefit equally in this context from lee effects.

TABLE I—DISTRIBUTION OF SURFACE WINDS, FORCE I AND CALMS BEING GROUPED SEPARATELY, IN HOURS

	NNE	ENE	ESE	SSE	SSW	WSW	WNW	NNW	Calms and force 1
Lindholme	123	129	120	123	237	369	444	342	1041
Finningley	342	138	192	186	507	402	408	276	477

The area is covered with drift soils which exhibit large and abrupt changes of type and characteristics (see Figure 1, facing). The two airfields are located on deep sand with a low capacity for moisture, and through which water drains rapidly—farmland on these islands of sand is often described locally as the "poverty acres". By contrast, immediately to east of Lindholme and also about 6 miles to north-north-east are areas of deep peat fen which are permanently saturated, even in the driest summer, and are unfit for cultivation. Additionally, there is to south and south-east of Finningley another area of deep peat, initially fen, which has been brought into cultivation by draining and warping and this also is permanently wet—chiefly because the embanked River Idle which flows through it maintains a high water table in the peat.

Although Mr. Smith[1] appears to consider that proximity to hill masses and to the sea is the only factor significantly varying the frequency of high humidity in a given air mass, he has found considerable inexplicable differences between stations in comparable locations[2], for example, Finningley and Church Fenton. It seems likely that the wet and dry areas shown in Figure 1 have some effect on the humidity régime at the two airfields. The observations of June–September, 1945, have been examined to seek some idea of its magnitude.

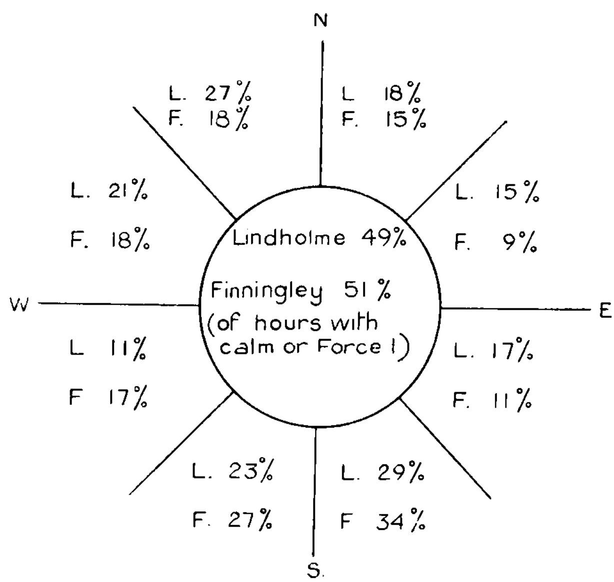

FIG. 2—FREQUENCY OF HIGH HUMIDITY, EXCLUDING OBSERVATIONS WITH RAIN OR DRIZZLE FALLING AT THE TIME, DURING JUNE–SEPTEMBER, 1945, AT LINDHOLME AND FINNINGLEY, REFERRED TO THE WIND REPORTED BY FINNINGLEY

Figure 2 has been constructed by

(i) excluding observations which were accompanied by rain or drizzle, as the effects due to transpiration and evaporation from soils are being sought,

(ii) tabulating the occasions when the relative humidity was 90 per cent or above according to the accompanying wind direction, the inner circle being utilized when the wind was calm or force 1, and

(iii) expressing these occasions as percentages of the total number, regardless of humidity, of such winds unaccompanied by precipitation. But as Table I shows that in 1945 the anemometers at Lindholme and Finningley were not equally sensitive and well exposed, and that the anemometer at Finningley was the more sensitive, the humidities reported from each airfield have throughout been referred to the wind observations from Finningley in order to avoid distortion of the statistics, and to facilitate comparison.

In drawing the following conclusions from Figure 2, it should be borne in mind that the rainfall during the period under consideration was 85 per cent of the normal value of 6·5 inches:

(i) Diurnal cooling results in high humidity at both airfields during 50 per cent of the periods of light winds, from June to September.

(ii) The driest winds were from NE. to SE., despite their track over the North Sea: this conflicts with Mr. Smith's findings[2]. But Lindholme was appreciably damper than Finningley, the air having passed over Hatfield Moor.

(iii) NW. to SW. winds were also dry after crossing the Pennines, but W. to SW. winds were much drier at Lindholme than at Finningley, the air having passed over some six miles of dry sand.

(iv) The most moist winds were from SE. to SW.: this is not surprising as they would have been mainly with subtropical air masses approaching from S. to WSW., but it again conflicts with Mr. Smith[2]. It is interesting to note the extremely high value of 34 per cent at Finningley after the air has passed over the fen-like "carrs" alongside the River Idle.

(v) With winds from NW. to N. there is a substantial drying out at Finningley, as compared with Lindholme, after the air has passed over some seven miles of dry sand.

It is considered that the statistics above demonstrate that the characteristics of the soils, in this area at least, substantially modify the frequency of high humidities which may be expected in an air mass, and that the order of magnitude of the modification is comparable with that due to hill masses. This may well be the cause of the anomalies mentioned by Mr. Smith[2].

A. M. YOUNG

Royal Air Force, Bawtry, Yorkshire, 8 *March* 1957.

[Mr. J. Findlater has independently drawn attention to the possible effect of the marshland near Lindholme on the relative humidity at that place. —Ed. *M.M.*]

Reply by L. P. Smith

I am very pleased that Mr. Young has found an explanation for these local differences. Clearly, the effect of the surrounding vegetation would be greatest at the end of a dry summer. It would be interesting to know whether the difference in relative humidity is due to a change in temperature or a change in water vapour content—presumably both? The agricultural branch of the Meteorological Office are at present examining the hourly humidities from 30 stations in the north-west Midlands during the years 1942–46, and it is to be hoped that similar results will be found.—L. P. SMITH.

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METEOROLOGICAL OFFICE DISCUSSION

Fog forecasting

The discussion held at the Royal Society of Arts on Monday, 21 October 1957, was opened by Mr. W. E. Saunders and Mr. R. J. Ogden.

Mr. Saunders dealt with forecasting the onset of water fog, the rate of decrease of visibility once fog has formed, and the clearance of fog. Purely theoretical approaches to the problems could be made, but led to equations which were cumbersome for ordinary use and which contained constants which were difficult to determine. Our methods were therefore based as far as possible on the known physics, but we used quantities which were known or measured. Experiments by L. P. Smith[1] comparing different specimens of the thermometers in use at outstations had suggested we might not be able to obtain forecast errors of less than about 1°F. Mr. Saunders then described various methods which had been evolved in this country during and since World War II. With regard to the method due to W. C. Swinbank[2], he was not aware of any wide testing, but it seemed it might make insufficient allowance for the actual water vapour content of the air. A more popular approach had been that of forecasting the fog point and night cooling by separate methods. After explaining the reasons for careful definition of the fog point, Mr. Saunders suggested it should be "the screen level temperature at which the general visibility falls within the fog range with relative humidity 95 per cent or more, or at which, with visibility already in the fog range, the relative humidity rises to 95 per cent or more". A slide was shown illustrating that the fog point is an air-mass property, nearly the same from place to place over large areas. Details were then given of the condensation level method[3] for forecasting the fog point, which Mr. Saunders said had been developed from an earlier method proposed by Briggs[4]. Details were given of the main results of a test of the condensation level method[5,6] carried out at 63 United Kingdom airfields in 1956. 28 stations had obtained mean forecast errors of not more than 1°F., and at 48 stations it did not exceed 2°F. The frequency of various errors at these 48 stations showed that 1°F. was not exceeded on 67 per cent of the nights, while one could expect errors of not more than 2°F. 87 per cent of the time. Variation with temperature showed that errors increased slowly with decreasing temperature below 32°F. State of ground is important—errors over both frozen and snow covered ground were nearly twice as great as over dry or wet soil. Rainfall in the afternoon caused some decrease in accuracy. Turning to forecasting methods for night cooling, Mr. Saunders described McKenzie's[7] method, and an adaptation of this type of method by J. M. Craddock and D. Pritchard[8] for forecasting the night minimum over a large area. This latter approach had led to mean square errors of 3·4°F. when applied to the records for 25 stations. K. Pollard[9] had shown that the McKenzie method could be applied to Wittering, with seasonal constants, giving a mean square error of 2·15°F. Mr. Saunders thought all these methods might omit some significant parameters. He spoke next of the method[10,11] based on the evening temperature discontinuity near the ground. It was stressed that this change in rate is very pronounced at the grass level. At Exeter, for 46 clear sky and light wind evenings in 1954, the average grass level change of rate was from 7·2 to 0·2°F. an hour. There could be no doubt that a major change takes place at that time in the conditions promoting cooling near the ground, and that we should treat the screen level cooling before and after this time by different methods. The annual variation of the time of discontinuity was illustrated by a diagram produced by W. J. Bruce[12] for Wahn, Germany. The screen level temperature (T_r) of the change of rate is given by a regression equation in the form $T_r = \frac{1}{2}(T_{max} + T_d) + C$, where the constant C varies according as there is or is not a subsidence inversion near the ground, and also varies slightly from place to place. Details given for five airfields showed that in general this method gives T_r within one degree. In our treatment of the subsequent cooling (that is after the change of rate) account was taken of soil characteristics by preparing individual sets of curves for each station. For the light wind cases we regarded the temperature itself as the main parameter, by plotting T_r againt T_{min}. The resulting curves were then used for forecasting T_{min} from the forecast value of T_r. This approach takes account[13-16] of three physical facts—the decrease in the net outgoing radiation with decreasing temperature (2½ per cent per °C.), the latent heat difference between dew and hoar frost, and the additional latent heat release which commences as soon as freezing of the soil moisture begins. The importance of these factors was brought out strongly by the Exeter $T_r - T_{min}$ curves for winter. The curvature of these showed that if T_r is 50°F. the amount of subsequent cooling is 16 degrees; if T_r is 40°F. it is reduced to 14 degrees; if T_r is 30°F. it is only 10 degrees. These curves did not allow for snow cover—this had been investigated for Alston, Cumberland, by W. E. Richardson[17]. Corrections for cloud cover were given in a paper by W. D. Summersby[18]. Tests of this method had given mean square errors of 1·28 at Northolt, and 1·4°F. at Weston Zoyland (using Exeter curves). In all these methods the accuracy depends, of course, on accurate cloud and wind speed forecasts. Turning to the rate of decrease of visibility in fog, Mr. Saunders said one result of Dr. Stewart's[19] analysis of Cardington data had been that in water fog there is an abrupt change from visibility above 1500 yards to 50 to 200 yards. This was largely borne out by general experience. At Exeter he had found[20] visibility had fallen to 550 yards or less within one hour of fog formation in 96 cases out of 112. The present position seemed to be that one had to forecast visibility falling into the lower part of the fog range from the time fog was expected to form. Two circumstances which aid a rapid fall of visibility are a short land track of the air mass and a wet ground. Regarding fog clearance, Mr. Saunders drew attention to the fact that on 40 nights out of 50 at Exeter water fog had cleared soon after the arrival of a sheet of cloud over the fog during the night. The cloud was not due to lifting of the fog. The significant temperature change was a marked rise at the grass level after the arrival of the cloud. The figures given were not the complete picture, because the fog had to be thin enough vertically for the arrival of the cloud to be observed. This probably meant that every case in which the depth of fog had exceeded about 300 feet had been omitted. Going on to the diurnal clearance of water fog, Mr. Saunders gave details of G. J. Jefferson's[21] method. This gave good results, but there were difficulties associated with the lack of reports of the depth of fog. Mr. Saunders then showed a diagram in which the time interval between sunrise and fog clearance was plotted against the date. The cases were separated according as the sky was or was not reported as obscured at 0600, as some criterion of the vertical thickness. This gave a reasonable separation, and the resulting curves could be used to forecast clearance times within one hour in a large proportion of cases from March to early November. In winter it had to be faced that fog which was initially thick would not clear at all through diurnal heating, and clearance could only be forecast when some general synoptic change could be foreseen. Mr. Saunders thought further progress in this field would depend on methods being developed for measuring the depth of fog at airfields.

Mr. Ogden spoke of the problem of forecasting visibility in smoke.

Visibilities of less than 200 yards had been observed with low relative humidities at Northolt[22] and at London Airport, and no doubt other airfields had similar troubles.

Dealing first with the smoke itself, Mr. Ogden described some results of the Leicester Report based on 1937–1939 data[23]. This showed that smoke which causes visibility reductions is partly industrial and partly domestic in origin. The larger particles, due to incomplete combustion, were more important than the smaller combustion nuclei[24,25]. In 1925 it had been found that over two-thirds of London smoke was due to domestic fires [26] and a similar result emerged at Leicester. These figures do not depend entirely upon the amount of coal burned; in the Leicester suburbs about twice as much smoke was produced per ton of coal burnt as in the city centre because of the inefficiency of the domestic grate, particularly after it has just been lit. Over the country as a whole, about one-third of the coal was used domestically, so that about half the smoke was of domestic origin. These figures are all pre-war, and one can only guess at the extent to which recent efforts to reduce industrial smoke and to use smokeless fuel domestically may have been offset by the post-war spate of house building.

Dealing with the seasonal variation of smoke, Mr. Ogden said the curve of mean monthly concentration showed a maximum in December and a minimum in June to July. The year could conveniently be divided into winter (November to March) and summer (May to September) with April and October as intermediate months in which artificial heating is in partial use. The winter: summer ratio of mean monthly smoke concentration at stations a few miles from a town centre is about 2 : 1 and of maximum monthly concentration to minimum about 3 : 1. This accords with general experience of smoke visibility troubles.

In addition to the yearly cycle of smoke pollution there is a weekly cycle due to human habits. At weekends industrial smoke is curtailed particularly in the city centre, but in the suburbs the Sunday to weekday ratio of smoke is about 8 : 10. Figures comparable with this latter reduction have been published for the visibility at Finningley [27]. However, in a purely domestic area, more smoke might be produced on Sundays than on weekdays; this was borne out in a report on Seattle, Washington [28]. Introduction of a five-day week suggests that Saturday will be different from other weekdays.

Turning to diurnal variations, Mr. Ogden said there was a pronounced smoke maximum at about 0800 and a minimum at 0100 to 0500, with a secondary maximum at about 1800 and a secondary minimum in the early afternoon. This cycle is caused by diurnal variations of insolation and smoke emission. The diurnal variations of the amount of smoke and the amount of sulphur dioxide in the air were then shown in graphical form [23]. It is normally assumed that the amount of sulphur dioxide present is proportional to the weight of coal burnt. The curves for smoke and sulphur dioxide were in close agreement for most of the day, but there was excessive smoke between about 0600 to 0700 and 0900 to 1000 on weekdays. This is due to freshly lighted domestic fires which are the prime cause of the morning smoke maximum, but the absence of excessive smoke in the evening indicates that the evening smoke maximum is attributable to meteorological causes. A separate analysis of Sundays indicated rather smaller total amounts of smoke; the morning smoke maximum was at about 1000 and smoke was excessive even until 1500 but there was a very great reduction over amounts on weekdays between 0600 and 0800.

Turning next to meteorological factors affecting the daily smoke cycle, Mr. Ogden said that of the various movements of smoke once it had left the chimneys, the important ones were its translation down wind and vertical diffusion. This latter is controlled by turbulence, which for forecasting purposes is probably best dealt with through wind speed and vertical stability. With constant gradient wind there is a turbulence cycle corresponding with the insolation cycle. The late afternoon temperature fall increases the stability near the ground, and accounts for the evening visibility deterioration. The presence of an inversion at a low level but not on the ground will also inhibit upward smoke diffusion and could lead to unusually heavy smoke concentrations which might not have been expected if only suface conditions had been considered and this case requires special care[24].

As to the dependence of smoke concentration on position relative to source, the Leicester Report showed that between about 4 and 10 miles from the city centre the concentration decreased inversely as the distance; beyond about 10 miles, the rate of decrease follows an inverse square law. Clearly, the likelihood of smoke being thick enough to produce fog decreases rapidly down wind. The surface wind direction is a critical factor in visibility forecasting but the air trajectory becomes important in cases of very light wind, when smoke may be brought to an airfield from an unusual direction. Apart from position relative to smoke sources there may be special features about the position of an airfield which affect the smoke concentration there; valley sites for example, experience higher concentrations than open country, particularly if an inversion exists below the valley top[24].

The main factors which have a direct bearing on the amount of smoke at a particular station may be summed up as follows:

(i) the amount of smoke emitted, depending on the season, day of week and time of day,

(ii) the position of the station relative to smoke sources and topography,

(iii) the wind direction,

(iv) the turbulence, depending on wind speed and stability and the thickness of the turbulent layer.

It follows from consideration of these that random variations in visibility in smoke are due primarily to wind direction and turbulence.

Hence the best approach to smoke visibility forecasting seems to be a statistical one in which the parameters are wind direction, wind speed and stability near the surface, together with the depth of the turbulent layer in cases of turbulent flow beneath a low inversion. Such an approach does not seem to have been tried for smoke only although it has been tried for general visibility at La Guardia[29]. It only achieved marginal success there, but the method might give better results if applied to cases of smoke visibilities only. In the absence of statistics, the forecaster must fall back on experience, but it was stressed that this must be backed by a thorough understanding of the underlying physical processes. The exact times at which visibility deteriorations occur must be to some extent a function of the station itself since the smoke which causes deteriorations has to travel from the source to the station; this will affect particularly the times of the morning smoke maximum whereas the time of the evening maximum, being dependent on the insolation cycle will be fairly closely related to sunset at all stations. One difficulty about a statistical approach is that this calls for observations over long periods, but that over such periods we have secular changes. This is particularly true of smoke emission. Reference was made to changes as evidenced by observations in London[30] and Los Angeles[31] and a very striking example from Atalanta, Georgia[32] was cited. Hence statistical methods will have to be applied with great care, but it was thought that a selection of suitable periods for study should be possible.

Opening the general discussion, the *Director-General* said the theoretical formulae were useful for showing what is relevant, rather than for daily use. He asked the reason for the use of the expression given for the temperature of the evening discontinuity (T_r). Mr. Saunders said the change of rate was believed to mark the commencement of condensation at ground level. The expression seemed a suitable hygrometric one to begin with, and it had been retained because of the satisfactory results obtained with it at a number of outstations.

Mr. Evans showed slides giving the mean variation of frequency of visibility less than 220 yards, and of visibility 220 to 1100 yards at London Airport, and also the relation of fog to the day of week.

Mr. Veryard thought fog clearance due to the arrival of a cloud sheet should be predictable from earth temperatures. He asked if the theoretical equations could be used if we had adequate observations. Mr. Saunders agreed with the first point. He thought we might do better with a more comprehensive observational programme. The methods he had outlined were an attempt to make the best use of the present instrumentation and observing programme.

Mr. H. H. Lamb spoke of fog clearance. He thought night clearances under a cloud sheet might really be due to wind. He referred to an unpublished method for forecasting diurnal clearance of fog at Shannon, which seemed rather similar to the method outlined by Mr. Saunders. He had also noted cases of fog clearing under clear skies during the night, which might have been due to subsidence. In reply to the first point mentioned, Mr. Saunders stressed that cases of freshening wind had been carefully excluded.

Mr. F. Davies said that use of a thermogram on the ground had stressed the magnitude of the changes at that level.

The *Director-General* asked why it was so often forecast that fog would be slow to clear from industrial areas. The amount of radiation cut off is very small. Mr. Gold thought it might be that evaporation from droplets containing pollution may be less than from clean water particles. He asked if we had any observations of the sizes of the particles. Mr. Ogden replied that laboratory experiments in the U.S.A. had shown that increasing the pollution content of a water fog delayed its clearance and that this effect was most marked if the pollution was caused by incomplete combustion products such as are produced by a domestic grate[24]. In reply to Mr. Gold he said that he had no information about the sizes of the water droplets in a polluted fog.

Mr. Gifford spoke of the good results obtained with the Exeter cooling curves.

On occasions when the forecast night minimum for Exeter failed because of an inaccurate forecast of cloud amount or wind speed, it could often be seen that the anticipated night minimum did in fact occur at other stations where the cloud and wind conditions had been as expected for Exeter.

Mr. May said that fog persists longer in industrial districts because of insufficient wind to clear the smoke. Mr. Ogden replied that this was often so; the dispersal of a water fog as evidenced by a drop in relative humidity frequently left the visibility unchanged or even reduced due to a simultaneous increase in smoke concentration.

Dr. Stagg asked if there could be an examination of occasions of widespread fog on a synoptic scale. He thought we should study the broad factors first, before coming down to the local methods.

Mr. Sawyer said failures of forecasts of widespread fog were due to failure to forecast cloud amounts and winds accurately enough. He queried the statement by Mr. Evans that if thick fog had not formed by midnight it was then unlikely. Mr. Evans admitted that there were a few occasions when a clearance in the middle of the night due to synoptic reasons were balanced by occasions when fog developed late in the night, but felt that the majority of cases supported his statement.

Dr. Sutcliffe said fog point was an air-mass property. The use of upper air temperatures to find the fog point was in fact a generalized method, as required by Dr. Stagg. He did not think it would be a useful approach to try to produce generalized cooling curves. With regard to the delay in the clearance of smoke fog, it was due to the fact that solid particles do not evaporate.

Dr. Stewart spoke of observations of fog droplets at Kew. There were large droplets of size 20μ, and small ones of less than 10μ. Each contributed half to the opacity. After dawn the large drops evaporated first. Smoke alone cannot account for the observed visibilities. The Director-General asked if atmospheric pollution causes fogs to be more frequent. Dr. Stewart had the impression it does, but he was not sure.

Mr. Veryard asked what was the relation between fog densities in town and country. Mr. Craddock said there was always some pollution in this country, and local factors are vital. Mr. Unwin spoke of cases where fog built downwards from a smoke layer over the airfield at Catterick.

Mr. Imrie mentioned the case where, with forecast fog point below freezing, no fog formed during the night as temperature fell through the fog point, but fog did form when the fog point was reached on rising temperature after sunrise. Mr. Saunders recalled cases of this type at Northolt. It was difficult to sort out causes and effects there, because it happened about 0800 hours, which was the time of the morning smoke maximum. It was a point which could be better investigated at a rural airfield.

Mr. Bradbury spoke of the critical nature of wind direction for smoke fog. Mr. Ogden said that was certainly borne out at London Airport.

Mr. Wallington spoke of the additional parameters included in the methods discussed. One reason for the usefulness of the expression adopted for T_r might be that it gave a value very near the wet bulb temperature. He asked if there was any definition of the fog dispersal temperature. Replying to the last point, Mr. Saunders suggested it should be the surface temperature given on the tephigram by the dry adiabatic through the top of the fog layer.

Closing the Discussion, the *Director-General* recalled an occasion when on receipt of a forecast of fog in the evening a transatlantic liner berthed and discharged at once instead of waiting until the following morning, when much delay and inconvenience would have been caused. It was an example of the usefulness of fog forecasts.

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NOTES AND NEWS

Courses of training for climatological observers

Two courses, each lasting $4\frac{1}{2}$ days, were held in October 1957, at the Meteorological Office Training School, Stanmore. 45 observers attended, the largest number in recent years.

Instruction and discussions covered all aspects of weather observing and recording. Films and slides were shown, and talks given on some of the applications of climatological data. Special attention was paid to the work at Crop Weather and Health Resort Stations. The observers were introduced to the new forms for climatological returns which it is proposed to bring into use in 1959 to facilitate the punching of the data from climatological stations on to Hollerith cards. Visits were made to the London Forecast Office and also to Harrow where the work of the British Climatological Branch, the recording of data on punched cards in the Marine Branch, and the testing of instruments were seen and discussed. The courses are designed to help the observers with their specific work, to broaden their interest in meteorology, and to give them an insight into the ultimate value of the observations. It is hoped to arrange similar courses in October 1958.

REVIEWS

Physics in Meteorology, By A. C. Best, O.B.E., D.Sc., 8 in. × 5 in., pp. viii + 159, *illus.*, Sir Isaac Pitman and Sons Ltd., London, 1957. Price: 18*s*.

Physics in Meteorology by Dr. A. C. Best is a recent addition to Pitman's "Applied Physics Series". The book has the purpose of "describing and explaining a selection of meteorological phenomena in terms familiar to the student of physics". A book which has this purpose has long been needed and in general the book satisfies the need. The chapter headings indicate the topics dealt with and are (i) meteorological instruments, (ii) the microphysics of cloud, precipitation and fog, (iii) radiation, (iv) atmospheric electricity, (v) wind, (vi) meteorological optics and acoustics, (vii) radio meteorology, and (viii) weather control. The order of the chapters is probably related to the author's interests, otherwise for example winds would ordinarily take precedence over atmospheric electricity. The chapters are, in general, independent reviews of the various subjects and their small relations to each other, and indeed often between different parts of each chapter demonstrate what a loosely knit subject meteorology is and how it must incorporate widely different fields of physics within itself.

For a book which covers such a wide range of topics the standard is high. In reading some chapters one gets the impression that the author has drawn heavily on standard texts or monographs, especially in fields where he is not himself an authority. This dependence is generally implied in the short but useful bibliography at the end of each paragraph.

The first chapter, on meteorological instruments, demonstrates most clearly the book's main defect. This is that too much has been attempted in too little space, and this chapter degenerates into a list of meteorological measurements rather than the account of meteorological instruments which the chapter heading suggests. One could make some detailed criticism of the chapter, but having regard to its condensed nature this might not be fair.

The second chapter on the microphysics of cloud, precipitation and fog, both by its position in the book and by its quality show Dr. Best's interest in this subject, but the next, on radiation, is not so up to date. Indeed, this chapter contains little of the advances which have been made in this subject since 1939. Since no review of more recent work written at the undergraduate level and making clear the physical processes involved has been made by anyone, Dr. Best is perhaps wise to treat the subject in the way he does.

Atmospheric electricity is well reviewed and the salient features are well brought out, but in chapter (v), the difficult but important topic of air movement is disposed of in only 13 pages. Meteorological optics and acoustics and radio meteorology are dealt with in a balanced way.

The final chapter on weather control is especially welcome. It is well done and strongly recommended.

To repeat, the main defect of the book is that too much is attempted and it is usually condensed and abridged too much. Perhaps the book ought to be reviewed by a student, rather than a teacher, because it is possible that condensation has been carried to the point where a student's interest is not held. There is so much in the book that serious omissions are rare; but surely it should have contained something about vertical stability and lapse rates? There is a short index in which, believe it or not, the word "latent heat" does not appear; does latent heat play so small a part in the physics of meteorology? The production of the book is good, but for its size, the price is high.

A. W. BREWER

Hygrometry. By H. Spencer-Gregory and E. Rourke. $8\frac{1}{2}$ in. × $5\frac{1}{2}$ in., pp. xv + 254, *illus.*, Crosby Lockwood, 26 Old Brompton Road, London, S.W.7. 1957. Price: 36*s.*

It was a shock to learn of the recent death of Dr. H. Spencer-Gregory and it has made this review harder to write.

The authors, who begin by dismissing the measurement of humidity in meteorology as "of little significance", claim to "examine the scientific principles involved in every known type of hygrometer". In point of fact several well known and important types of hygrometer are not even mentioned, the most striking omission being the infra-red absorption hygrometer. On the other hand the examination of the scientific principles of those instruments which do find a place is sometimes seriously misleading—notably so in the case of the dew-point hygrometer. It is deduced that, with all normal dew- or frost-point hygrometers, "errors (of vapour pressure) of as much as 25 per cent are to be expected". This result depends on an assumption that there is no movement of air near the cold surface other than molecular diffusion. No justification is given for this assumption; in every dew-point hygrometer known to the present reviewer it is certainly not true.

The treatment throughout is theoretical, not practical, and the mathematical argument can often not be followed in detail without a fairly wide physical background—including, for example, such things as "Pollitzer's quantum relation for this specific heat of ice".

The style in which this book is written is best illustrated by two examples: "Polarization effects are eliminated by virtue of the use of A.C. practice" and

"At temperatures below 190° abs. an effect has been noticed in the case where the thimble surface was cooled down to about 160° abs. relevant to moist air whose frost point was about 194° abs."

R. FRITH

METEOROLOGICAL OFFICE NEWS

Sports Activities.—*Athletics.*—In the Air Ministry Cross Country championship held at Epsom on November 30, 1957, the first and third places were gained by Messrs. R. A. Stratton and M. K. Garrod respectively. The team race was won by the Meteorological Office.

Corrigendum.—In the October 1957 number under *Academic successes* D. E. Lantry should read D. E. Langley.

OFFICIAL PUBLICATIONS

The following publications have recently been issued:—

Air flow over mountains. By G. A. Corby, B.Sc.

A brief survey is first given of the observational evidence regarding special air-flow effects in the neighbourhood of mountains, as provided by the visual evidence of clouds, the experiences of glider pilots and effects noted by the pilots of powered aircraft. In the discussion of theoretical work, mathematics has been avoided so far as possible, the emphasis being on the interpretation and implications of theory. The application of this knowledge to aviation forecasting is considered in some detail with the aid of numerous actual examples of the experiences of pilots in flying over mountainous terrain. Advice is given on the recognition of air streams favouring the occurrence of waves to the lee of mountains and, to the extent that the present state of knowledge permits, on the prediction of the characteristics of any such waves. The effect of mountains in generating turbulence and in modifying the liability to aircraft icing is also considered. In the final section, some further information, which is intended specifically to assist pilots, is given.

Some typical weather maps.

For many years the Meteorological Office has published a pamphlet called *Examples of weather maps*, which, effectively, is an extract from the *Weather map*. The pamphlet has proved valuable to schools and other institutions concerned with the teaching of meteorology, since it conveniently displays some typical examples of barometric distributions.

A new edition of *Examples of weather maps* under a new title *Some typical weather maps* has now been produced to meet the continuing demand. It incorporates the latest developments in meteorological practice and provides an excellent handbook in miniature to the student beginning his studies in synoptic meteorology. Coding and plotting are briefly described and salient points in the weather maps noted.

WEATHER OF DECEMBER 1957

Great Britain and Northern Ireland

In the British Isles December began with five days of fine, generally quiet, weather followed by an equal number of wet, stormy days. Thereafter a rather dull period with cool north-easterly winds was gradually replaced, between the 15th and 17th, by a south-westerly régime with changeable weather which dominated the second half of the month.

It was sunny in many places from the 1st to the 5th with widespread frost and fog during the early mornings. Air temperature fell to 19°F. at Birmingham on the 2nd, and on the 4th and 5th fog persisted throughout the day over much of the Midlands and southern England and became especially dense around London. In these foggy areas temperature remained about the freezing point all day—at Ross-on-Wye it did not rise above 29°F. On the 6th milder air accompanied by rain spread over the country from the north-west, clearing the fog, and that night, in sharp contrast to recent low temperatures, temperature at many places in southern England did not fall below 50°F. Vigorous depressions moved eastwards across Scotland on the 7th and 8th giving gales in all parts of the British Isles with gusts of 60 knots as far south as the Cornish coast. Rain was widespread and locally heavy; both Stornoway and Aberdeen recorded about 1½ inches in 24 hours. On the 11th an intense and complex depression was situated to the west of the British Isles, and small depressions formed on an associated occlusion as it moved slowly across the country. Gales were again widespread and rain heavy in places. Wind rose to 70 knots at Plymouth and during the afternoon a minor tornado, with violent winds, moved north-east to Devonport. At Scilly 1½ inches of rain fell between 0900 and 2100 G.M.T., and in 24 hours a similar amount was recorded at Leuchars and Aberdeen. After a temporary period of colder, dry weather during which high pressure spread south-east from Scotland, and many stations reported a return of frost and fog—temperature fell to 18°F. at Yeovil on the 15th and 16th —milder air from the Atlantic began once more to invade our north-western districts on the 15th, and two days later had spread to the whole country. Mild cloudy weather, with temperature locally rising into the upper fifties, persisted for nearly a week. On the 23rd a depression formed off our south-west Approaches giving rain with local thunderstorms in the south-west and Midlands, but in the north weather was mainly dry with light north-easterly winds, though there were areas of mist or fog; Glasgow was fog-bound for much of the 23rd and 24th. Christmas Day was bright and dry at many places in the British Isles, but cloudy rainy weather spread to our north-west districts during the afternoon with winds reaching gale force locally. Weather during the remainder of the month was changeable and generally mild, but cooler air, accompanied by sleet and snow, spread into Scotland during the last three days.

Temperature was above average in Scotland, taking the month as a whole, but slightly below average in England and Wales where the deficit was greatest during the first week. During the last week of the month temperature in England and Wales was somewhat above the average and more than 7°F. above the average in Scotland. Sunshine was above the average nearly everywhere. During the first week most districts of England and Wales had nearly twice their normal amount, but during the last half of the month there was a deficit in Scotland. Rainfall was generally below the average south of a line drawn from the Mersey to the Wash, in north-east England, the border counties of Scotland, locally in Lanarkshire and Perthshire, and over much of south-west Scotland.

Most out-door farm work was reasonably advanced at the end of the month, especially in the south. Winter spraying and pruning and general clearing of orchards were well up to schedule. Very advanced greens showed quite heavy frost damage early in the month, but later planting appeared untouched. In general, early winter work in the countryside was well in hand.

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

	AIR TEMPERATURE			RAINFALL		SUNSHINE
	Highest	Lowest	Difference from average daily mean	Per-centage of average	No. of days difference from average	Per-centage of average
	°F.	°F.	°F.	%		%
England and Wales ...	60	12	0·0	83	−3	123
Scotland	58	10	+0·1	114	−2	139
Northern Ireland ...	57	20	+0·5	132	−1	125

THE WEATHER OF OCTOBER 1957

Northern Hemisphere

The Icelandic depression was near its normal position but much deeper than normal, whilst the Azores high was a little north of its normal position and of about normal intensity. The Siberian anticyclone was near normal, in both position and intensity. Pressures were, however, above normal over Europe so that a ridge of high pressure linked the Siberian and Azores anticyclones. In the Pacific sector the Aleutian low was a little to the west of the normal position but of average intensity. The Pacific anticyclone centre was weaker and further south than is normal.

The pressure was higher than normal over the greater part of North America and in the extreme north-west of Canada anomalies reached + 10 millibars. Pressure was about 6 millibars higher than normal off north Siberia and there was an anomaly of − 15 millibars north of Jan Mayen.

The north-westerly air flow over Labrador was much more pronounced than is usual. Over the North Pacific Ocean and over much of Asia the circulation was sub-normal.

The largest temperature anomalies occurred in polar regions and in the extreme north of Siberia reached −6°C. although temperatures were about 5°C. above normal between Spitsbergen and East Greenland. Over most of northern and central Europe temperatures were a little above normal but the air was slightly cooler than usual over the western Mediterranean and North Africa. Over the Rocky mountains and most of the United States temperatures were generally below normal.

Rainfall was less than normal over Central Europe but more than normal over the Mediterranean lands and North Africa. Rainfall was also more than normal in a well marked zone extending from Scandinavia across Siberia.

RAINFALL OF DECEMBER 1957

Great Britain and Northern Ireland

County	Station	In.	Per cent. of Av.	County	Station	In.	Per cent. of Av.
London	Camden Square ...	1·68	70	*Glam.*	Cardiff, Penylan ...	2·40	48
Kent	Dover	1·72	56	*Pemb.*	Haverfordwest	4·22	74
,,	Edenbridge, Falconhurst	2·73	83	*Radnor*	Tyrmynydd	5·17	63
Sussex	Compton, Compton Ho.	3·64	87	*Mont.*	Lake Vyrnwy	5·55	79
,,	Worthing, Beach Ho. Pk.	1·79	59	*Mer.*	Blaenau Festiniog ...	11·04	87
Hants.	St. Catherine's L'thouse	3·44	109	,,	Aberdovey	2·75	58
,,	Southampton (East Pk.)	2·10	57	*Carn.*	Llandudno	2·48	86
,,	South Farnborough ...	2·20	76	*Angl.*	Llanerchymedd ...	4·42	101
Herts.	Harpenden, Rothamsted	2·25	79	*I. Man*	Douglas, Borough Cem.	4·10	83
Bucks.	Slough, Upton	1·85	73	*Wigtown*	Newton Stewart ...	5·70	105
Oxford	Oxford, Radcliffe ...	2·53	103	*Dumf.*	Dumfries, Crichton R.I.	4·72	110
N'hants.	Wellingboro' Swanspool	2·31	98	,,	Eskdalemuir Obsy. ...	6·22	89
Essex	Southend, W. W. ...	1·70	86	*Roxb.*	Crailing...	1·96	73
Suffolk	Felixstowe	1·94	93	*Peebles*	Stobo Castle	4·38	115
,,	Lowestoft Sec. School...	1·79	77	*Berwick*	Marchmont House ...	2·16	77
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