M.O. 507

AIR MINISTRY

METEOROLOGICAL OFFICE

METEOROLOGY OF AIRFIELDS

By C. S. DURST, B.A.

LONDON: HIS MAJESTY'S STATIONERY OFFICE

1949

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CONTENTS

PREFACE

This book is a digest of the answers given to many inquirers for information on the meteorological problems involved in siting airfields. These inquiries have led to a number of investigations being made on various aspects of applied meteorology, and it is thought that many will find it convenient to have in a compact form the information which is at present scattered rather widely in obscure files and minutes and which is not readily available to the general public without the initiation of an inquiry to a Ministry.

The manuscript was prepared during and just after the second World War. The reader's indulgence is asked for the anachronisms apparent in the references to many airfields which are now happily no longer in use. Since, however, they are used as illustrations of the physical laws which affect sites, the lessons still remain valid.

I am indebted to the Director, Meteorological Office, for permission to publish this book. The data contained in it have been derived from many sources and I gratefully acknowledge the assistance which the Directors of the Meteorological Services named in Appendix III have rendered by supplying the data contained therein.

For the compilation of many of the diagrams and tables I am indebted to members of the Climatological Branch of the Meteorological Office and in particular to Dr. C. E. P. Brooks, Miss E. E. Austin, Miss E. H. Geake and Miss N. Carruthers ; finally, I must most gratefully acknowledge the assistance of all the members of the Investigations Branch of the Meteorological Office who have furthered the progress of this book in so many ways.

C. S. DURST

July 1947

MAP SHOWING POSITIONS OF STATIONS IN THE BRITISH ISLES MENTIONED IN THIS BOOK

METEOROLOGY OF AIRFIELDS

INTRODUCTION

Many factors come into the siting and design of an airfield which are entirely independent of meteorology and are likely to be of paramount importance, but subject to these the meteorological survey falls into two categories. First, there is the broad climatological survey which embraces the district in which the airfield is desired. It is aimed at choosing the best possible site and is limited only by the extraneous physical restrictions which are imposed by these non-meteorological factors. Secondly, the site (or sites) having been chosen in the district the lay-out of the airfield requires a survey of a different and detailed character to decide how best to use the land available to the designer.

The purpose of the notes which follow is to set out the principles which have been applied in giving advice on the siting of airfields and to give statistics which at least are a sample of the data available. It is clearly impossible to include all the many data which would be needed for the correct planning of every conceivable airfield even on the main trunk routes of the world, but it is hoped that the examples provided may give an indication of what is available and of the methods by which, even when no observational data can be found, an approximate answer can be given by deduction to the more important questions which the airfield designer will need to ask.

The information is set out under the meteorological elements of visibility, cloud, precipitation, wind, pressure and temperature as being the most convenient form of classification. In the visibility section it has been necessary to enumerate the physical processes which lead to poor visibility, in order that at any site it may be possible to assess what meteorological conditions must be allowed for, so that, if alternate airfields are planned, the alternative may be likely to be available when the principal airfield is weather-bound. Similarly, cloud has to be treated with the physical processes ever present in the mind. The consideration of these elements leads on to the statistical analysis of flying-fitness figures which are devised to embrace the combinations of various grades of visibility and cloud height.

Precipitation is dealt with by giving data which may be of use in designing the drainage lay-out of the runways and perimeters. Some consideration too is given to the hampering effects of snow, so that allowance can be made for the provision of snow-clearance equipment.

Data of the extremes of wind are of importance in the consideration of pressure on buildings ; also winds are a factor in assessing the danger of vertical currents over the approaches to airfields. Finally in the design of the lay-out of runways the frequency of directions and speeds of the wind are of primary importance, and a method is set out by which the orientation of runways may be best designed.

The design of runways too needs the meteorological data of pressure and temperature so that the most efficient runway length may be laid down. This is treated in a separate chapter.

CHAPTER I

VISIBILITY

The visibility at a site is affected by :

(*a*) Waterdrops due to the cooling of the atmosphere below its dew point or to the mixing of air masses with critical humidities.

(*b*) Smoke or dust particles carried from neighbouring sources.

(*c*) A combination of (*a*) and (*b*).

(*d*) Rain or snow.

Fogs (and mists) which result from (*a*) may be classified, according to the method by which the cooling takes place, into radiation fogs, sea fogs, advection fogs, hill fogs, and frost smoke.

§ 1. RADIATION FOG

In principle low-lying and damp valleys are particularly liable to radiation fog but coastal areas are not. The reason for the coastal areas being most free is the tendency for the sea to maintain the air at constant temperature ; hence if there is a gentle wind off the land the coastal strip will in most cases not gain the same benefit as if there is a wind off the sea. A flat and waterlogged region is very liable to radiation fogs. The region most free from radiation fogs is probably one situated within a mile or two of the sea, backed by hills within about two or three miles. At such a site the sea usually tends to keep temperature up, and on calm quiet nights, when there is an off-shore drift which might bring fog off the land, any air from inland has had to flow down from the hills and in so doing is compressed in descent and warmed adiabatically. Moreover when the drift is light it is reinforced by katabatic effects, and in general movement is an enemy to radiation fog.

Such a combination of topographic features is reported from parts of the south coast of England, for instance between Portsmouth and Bognor the Downs lie behind a strip of flat ground running towards the English Channel ; this strip varies in width from only a mile or so near Emsworth to about 10 miles at Selsey Bill. The three airfields of Thorney Island, Tangmere and Ford have differing situations, and the percentage annual frequency with which they have fog (visibility less than 1,100 yd.) is given in Table I (Gatwick being included as an inland airfield in the same district).

TABLE I—ANNUAL PERCENTAGE FREQUENCY OF FOG

Visibility less than 1,100 yd.

Station	Period	Time of observation					Mean of observations at 0100, 0700, 1300, 1800
		0100	0400	0700	1300	1800	
				per cent.			*per cent.*
Thorney Island . .	Sept. 1939– Dec. 1944	4	4	4	2	3	3
Tangmere . .	Nov. 1939– Dec. 1944	5	5	6	2	4	4
Ford	Nov. 1940– Dec. 1944	7	9	7	2	4	5
Gatwick . .	May 1936– Dec. 1938	–	–	7*	2	1	(4)

* Observations at 0800 G.M.T.

At Thorney Island there is little distance between Chichester Harbour and the Downs, and hence the moderating influence of the sea is felt to the full whereas drainage tends to keep up circulation. At Tangmere the airfield is close under the Downs and some distance from the sea, hence radiation fog forms at night. Observers on the spot report that it is often possible to see a clearing of the early morning fog which is due to the tendency of katabatic winds to flow off the hills and set up circulation. At Ford however the effect of radiative cooling in producing fog is little checked by the katabatic wind off the Downs.

A local note at Tangmere states " Diurnal heating will frequently prevent the landward penetration of sea fog during the day with an on-shore wind. At sunset the foggy air commences to drift in (and is further cooled by radiation), visibility falling from several miles to below 1,000 yd. at Tangmere in a few minutes. With a gradient wind of 130° to 180° and less than 13 kt. (15 m.p.h.) this frequently does not take place. The south-easterly surface wind at dusk is observed to back to E. and then NE. in about an hour, thus preventing the on-shore drift of the sea fog.''

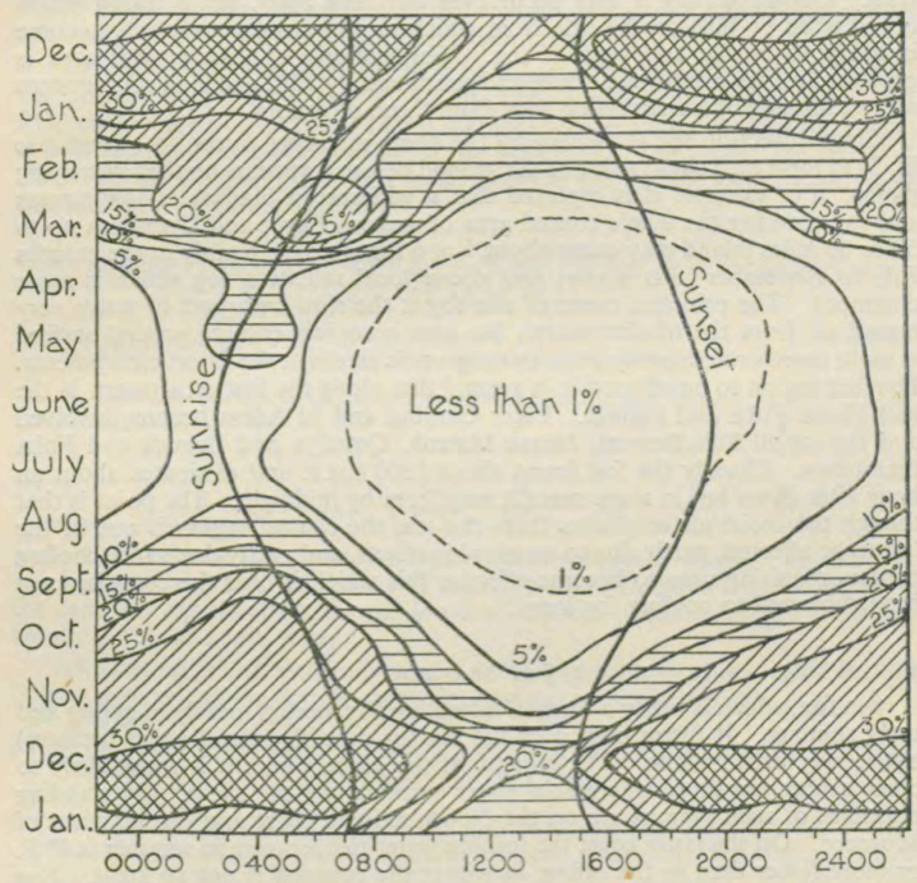

FIG. 1.—DIURNAL SEASONAL ISOPLETHS OF FREQUENCY OF MIST (VISIBILITY <2,200 YD.) AT MILDENHALL

Period September 1939 to August 1945

Radiation fog is seen in its most marked form over flat country with a slight drainage from low surrounding hills. As an example of an inland site where radiation fogs and mists are common may be mentioned the airfield at Mildenhall, statistics for which are given in Fig. 1. In damp areas the moisture evaporated by the surface during the day is apt to increase the density and frequency of radiation fog at night, for example at Weston Zoyland on Sedgemoor low-lying radiation fogs are very common on summer mornings but they " burn off " soon after the sun gets up. Other examples of the same type are the low-lying evening mists one often sees over meadows which not infrequently only extend a few feet from the ground and in which cattle appear to be floating. Many more notable instances might be quoted. Suffice it that at Mingaladon airfield, Rangoon, fog and mist forms night after night during the SW. monsoon season but clears soon after sunrise. Statistics compiled on observations made an hour or two later show no sign of fog.

§2. ADVECTION FOG

Advection fog is due to air of high dew point being carried over cooler ground. A special form is thaw fog when mild air comes in after a prolonged frost. Geographically it may occur over any land mass, but a region which is protected by hills on the side from which moist currents are likely to come is likely to escape this type of fog. For example the Sedgemoor area is protected on the south-west, south and south-east by hills, and is in consequence almost immune from advection fogs from those directions.

Since advection fog is assisted by the damp air being forced to ascend it is likely to form on a slight rising of the ground before it appears on the lower-lying plains. For example it is reported that a widespread blanket of low stratus and fog covering the whole coastal area of western Egypt and Cyrenaica up to 50 or 80 miles inland may occur about 5 or 6 times a year mainly in the months July to November (this is over and above local radiation fog which is more common). The principal cause of this fog is the slow transport of warm very humid air from the Mediterranean Sea over a rapidly cooling ground surface at night together with cooling due to orographic ascent at the desert escarpments. The first region to be affected is in general that along the first escarpment in the east above Fuka and Bagush. Later Gambut and El Adem become involved and last of all Sidi Barrani, Mersa Matruh, Qotafiya and Bagush and Fuka themselves. Usually the fog forms about 0300 L.M.T. and dissipates about an hour after dawn but in some cases it may form by midnight. The point is that though the moist air originates from the sea, the coastal region is one of the last to be affected, partly due to orographic effects, and partly due to the cooling process requiring time to become effective (air which is over the coast has not been subjected to cooling for long).

§3. SEA FOG

Sea fog, which is really a form of advection fog, occurs mainly in spring and early summer. It forms only over the sea (or possibly inland water surfaces) but it may drift inshore. The regions of the globe where it is most likely to come ashore are those where cold water currents hug the shore. Outstanding examples of such regions are on the Newfoundland coast and on the coast of Morocco. Off the latter coast the inshore water temperature in summer is 4° F. or more lower than in the offing, in winter the contrast is not so great. Fog over inshore waters is very common, and any on-shore wind is liable to bring it in either as a ground fog or as stratus at a very low height ; for example the following note by an experienced pilot on the approach to Ras el Ma may be quoted : " the prevailing wind from the WNW. creates a sort of fog on the coast which is in reality stratus cloud and which forms several miles out to sea and spreads over western Morocco as far as Tarza. At the coast the ceiling is generally between 100 and 350 ft. following the contour of the ground inland. . . . Towards 1000 G.M.T. the heat of the sun causes the clouds to rise and break up. . . . Towards evening the clouds frequently descend and reform but rarely do they extend inland beyond Tiflet."

§4. HILL FOG

Hill fog is often due to lifting (and consequently cooling) of the air by forced ascent up the hill slope, in other cases it may be due to cloud formed elsewhere drifting over the high ground and enveloping it. High ground above say 1,500 ft. is on the whole worse than low ground for fog. The worst position of all is a comparatively large isolated mass of high ground in a region where the prevailing wind blows off the sea. On the other hand mere elevation above sea level does not of itself imply a large fog frequency; for example over a high plateau the general level of the cloud base is very likely controlled by the height of the plateau so that it will be no more likely to reach to the ground than is cloud liable to descend to sea level on flat coastal plains.

To emphasise the importance of the increase of fog with height figures from the British Isles and from Austria may be quoted.

The percentage frequency of morning fog was recorded at many stations in the British Isles during the winter of 1936–7 and the average percentage frequency of fog (visibility less than 1,100 yd.) was computed for various heights in two regions Devon–Cornwall and the Midlands. The results are shown in Table II, the figures in brackets indicating the number of stations on which the percentage figure was based.

TABLE II—MEAN PERCENTAGE FREQUENCY OF WINTER FOG AT STATIONS AT VARIOUS HEIGHTS ABOVE M.S.L.

Height (ft.)	0–99	100–199	200–299	300–399	400–599	600–799	800–999	1,000 and over
Devon and Cornwall	1 (11)	3 (11)	5 (14)	5 (13)	5 (9)	7 (4)	11 (3)	26 (2)
Midlands	15 (30)	11 (34)	13 (61)	14 (41)	15 (54)	16 (10)	18 (3)	25 (2)

In both cases there is a decided increase in the frequency of fog above 600 ft., but the general greater frequency of fogs over the Midlands tends to decrease the contrast between the high- and low-level stations which is so apparent in the clearer air of the south-west.

Information is not available for the British Isles much above 1,000 ft., but figures may be quoted for the Austrian Mountains as follows :

TABLE III—AVERAGE NUMBER OF DAYS WITH FOG AT UNTERSBURG AT 5,500 FT. AND SALZBURG AT 1,400 FT.

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
						days							
Untersburg ..	12	12	15	13	15	15	14	13	13	10	6	11	149
Salzburg ..	6	4	2	0·8	0·4	0·2	0·1	0·3	3	6	7	7	37

These figures however can only be treated as specimens and not as typical examples to be applied generally ; fog in mountainous regions is so greatly dependent on the configuration of the mountains. What Table III does bring out is the winter fog of Salzburg, typically a foothill station and the summer fog of the high station which is due to cloud.

In Alpine valley bottoms and on the slopes at comparatively low levels fog is more likely in the early morning than later in the day. On plateaux at the higher elevations they are more likely at midday than in early morning or evening.

§ 5. FROST SMOKE

Frost smoke is a type of fog peculiar to arctic and antarctic regions. Sometimes called smoking water it occurs where very cold air flows over milder seas. In embryo it may often be seen over English rivers during cold spells, and takes the form of wisps of vapour rising from the water surface as the cold air is warmed near the surface, evaporates the water and carries the vapour into the colder air above. In Icelandic and Norwegian fjords and other regions where very cold air can drift over warmer water the frost smoke may fill the air with fog and drift inland smothering the countryside with a blanket up to a height of 500 ft. or more. As a typical example of this may be quoted the conditions at Kirkenes airfield in arctic Norway. In winter, when the land is very cold, air drifting over from south and south-east causes the fjord to become so filled with frost smoke that it makes the airfield unserviceable. Varanger Fjord is said to be very liable to frost smoke.

§ 6. FRONTAL FOG

Frontal fog is in reality cloud with its base so low as to reach the ground. With fast-moving fronts it may last for half an hour to an hour, with sluggish fronts for several hours. It is likely to be worse on high ground than on low. Some protection from it may be gained on the leeward side of moderately high ground, for instance in the British Isles frontal fog arriving from the west rarely affects the Shropshire airfields.

In addition to frontal fog cumulonimbus clouds sometimes have their bases so low that they cause fog even at sea level. In the British Isles this is not likely to occur often except on the north coast of Scotland during very unstable polar outbursts, and on the north coast of Norfolk with northerly or NNE. winds, but it is a fairly common feature of the coast of north-west Germany. In monsoon regions it is much more common, and in a bad monsoon squall the rain is likely to reduce visibility to less than 1,000 yd. but the duration is comparatively short. Table IV gives the average percentage of occasions with visibility less than (*a*) 1,100 yd. and (*b*) 2½ miles in the various seasons at certain places in India based on morning and afternoon observations.

TABLE IV—PERCENTAGE FREQUENCY OF (*a*) FOG AND (*b*) MIST AT VARIOUS INDIAN STATIONS

(*a*) Visibility less than 1,100 yd.
(*b*) Visibility less than 2½ miles

	NE. monsoon Nov. to Feb.		Hot season Mar. to May		SW. monsoon June to Aug.		Post monsoon Sept. and Oct.	
	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)	(*a*)	(*b*)
Karachi	0·5	4	0·0	2	0·0	1	0·0	2
Bombay	0·1	2	0·0	0·5	0·9	5	0·2	1
Agra	1	24	0·1	10	0·2	7	0·0	4
Nagpur	0·4	2	0·0	0·7	0·1	10	0·0	5
Calcutta	12	83	0·7	28	0·7	26	0·8	39
Madras	0·4	3	0·2	0·7	0·0	0·4	0·2	1
Colombo	0·1	1	0·0	1	0·0	0·5	0·0	0·5
Akyab	0·5	6	0·8	7	2	25	0·8	9
Sandoway ..	0·4	2	0·4	4	2	25	0·7	10

The reduction of visibility below 1,000 yd. by monsoon cloud clearly only occurs frequently on exposed coasts, e.g. Akyab and Sandoway, and there it can be expected during about 2 per cent. of the time. But monsoon conditions limit visibility to less than 2½ miles for a quarter of the time in those places.

Other places are included in the table by way of contrast. Calcutta is outstanding for fogginess during the NE. monsoon when visibility is reduced by radiation fog on nearly one night in three.

§ 7. SMOKE FOG

Smoke and dust fogs are mostly man made, a fact particularly unfortunate in their relation to airfield sites, for so often the nearer the site is to the population centre it serves the worse is likely to be the pollution. But pollution may travel far. In south-east England the pollution of industrial Belgium and north-east France brings down the visibility with SE. winds. Perth and Errol are affected by the smoke of Glasgow and that smoke has even affected flying at Aberdeen in certain conditions. The effects of Glasgow smoke are a good example of the concentration which topography helps to maintain. In its travel north-eastwards the Glasgow smoke is unable to spread laterally, hence it arrives over the Tay in a more concentrated form than had it flowed over open country. The canalization of the valleys also induces a more frequent flow of air from the Glasgow area to the Tay than would occur if the country had been all flat. From the same cause a mountain mass may protect its further slopes from the pollution produced on its windward side as is seen in the comparative immunity from serious smoke pollution enjoyed at Leuchars.

The degree to which smoke affects visibility is dependent on the amount of pollution put out by the source. The smoke of London affects visibility to such an extent at about 50 miles from the suburbs that observers generally mention it in a census of smoke-pollution sources. Beyond that distance their notes are rather undecided, and it may be concluded that London smoke does not often affect distances greater than 70 miles.

Norwich (population 125,000) is a pollution source which is well isolated from others, and from a detailed examination[1*] it was estimated that the pollution of the town was appreciable at a distance of 4 miles in spring, 5 miles in summer and autumn and 6 to 7 miles in winter.

Some rather rough calculations of the effect of smoke on visibility based on an extrapolation of these measurements gave the following results. If a given set of conditions produces a reduction in visibility on account of smoke to 500 yd. near London it would reduce visibility to about 1,500 yd. at 15 miles out and to about 3,500 yd. at 25 miles. The same type of conditions would produce a visibility of about 2,000 or 3,000 yd. on the immediate outskirts of a town like Norwich. Bristol (population 400,000) might be expected to give a visibility of about 2,000 yd. at 5 miles down wind under similar conditions.

Putting this in a different way, on a day when the general visibility in country districts in eastern England is 6 miles the visibility would be about 2½ miles just outside Norwich and about 1,100 yd. just outside London.

The following are notes which have been supplied by meteorological officers on the effect of smoke on visibility at airfields. They are only one or two typical reports from a very large number.

Linton (*Yorkshire*).—York (population 85,000), distant 8 to 10 miles south-east and south-south-east, does not reduce horizontal visibility seriously, but it may produce a haze layer which reduces air-to-ground visibility sufficiently to obscure lights on the airfield from above at night. Leeds (population 480,000) and Bradford (population 300,000), distant 20 to 25 miles south-south-west and west-south-west, may reduce horizontal visibility in a south-south-west to west-south-west direction by 50 per cent., i.e. visibility may be 6 miles to the

* The index figures refer to the bibliography on p. 67.

north-west and south-east but 3 miles to north-east and only 2,000 yd. to south-west. It may produce a haze layer obscuring the airfield at night, in the evening and in the early morning. Darlington (population 72,000) and Teeside (population 250,000), distant 35 to 40 miles to north-north-east and north-north-west, affect visibility when there is a light NE. gradient. Then the winds near the surface at Linton are usually N. or NW. and sometimes a bank of smoke (carried by the NE. wind aloft) appears to the west of the airfield ; this reduces visibility for an approach from the west.

Ringway.—A chimney 400 yd. south gives pollution but not very frequently. Industrial Lancashire, distant 2 to 20 miles to the west and north-west, affects visibility seriously especially when there is a surface inversion. Then the pollution is trapped against the Pennines in a pocket and may persist all day. Manchester (population 750,000), distant 8 miles north and north-east, gives very thick pollution especially in light winds. The smoke from the Midlands 50 miles to the south is only apparent in an air stream persistent over a period of time dependent on the wind speed.

Digby.—The effects of smoke from Lincoln (population 66,000), distant 12 miles, and Grantham (population 20,000), distant 18 miles, are slight, but those from Nottingham and Derby, 40 miles west and west-south-west, are very marked at times.

Wyton.—Here local smoke is of little importance but over Huntingdonshire generally Midland smoke which has travelled 70 miles may reduce visibility at times to 1,500 or 2,000 yd.

Hendon.—Factories ½ mile south of the airfield together with the effect of London often reduce visibility to less than 1,000 yd. with winds from south. A freshening of the wind may produce appreciable improvement.

One other aspect of smoke must be mentioned. In the tropics during dry seasons bush fires are apt to give rise to vast areas of smoke and this smoke travels many miles, affecting visibility to a serious extent.

§ 8. DUST AND SAND FOGS

Dust and sand fog are mainly confined to arid countries. Large-grained sand is only stirred by winds of force 4 or more. The sand movement increases rapidly when winds reach force 6, then the grains are carried horizontally and if they strike an object, even a comparatively small stone, they bounce upwards but are not supported in the air and fall back again.[2] Hence the true sand fog is no more than 3 or 4 ft. deep ; often a man can stand with the sand streaming past him and his head protruding into clearer air. To the aircraft coming in to land the ground surface may be blanketed but hangars and buildings stand out.

It is when the ground surface consists of fine-textured loose soil that the really serious duststorms occur. For siting airfields in such country a survey of the soil conditions is necessary over a wide area around the site and information obtained as to the prevailing winds. If possible the wind data should not be confined to direction alone, speed is important for the dust-raising power of wind varies with speed and probably not merely directly with the speed but according to some power law. Traffic on the windward side of such an airfield may cause trouble, but that can be overcome by suitable precautions. The more extensive the area of loose soil is the greater the problem.

As examples of the great duststorms of the desert may be quoted the haboobs of the Sudan and the duststorms of Iraq. The former are really frontal phenomena due to gusty winds and the haboobs occur when the cold front arrives over a region where the soil is dry and powdery ; the gusty wind fills the air with dust and the violent convection in and below the cumulonimbus

clouds of the cold front carry the dust high into the air so that the whole atmosphere to perhaps 10,000 ft. is filled, and the bad visibility may extend over an area about 20 miles or more across and of considerable length. The duststorms of Iraq are even more serious than the haboobs ; they may be very widespread with the north-westerly winds of summer when they blow at 15 kt. or more gusting to at least 20 kt., but the worst storms by far are those associated with SE. winds of force 6 to 8 that occur in winter and spring.

On the other hand local duststorms are often raised, as for instance the " summer type " duststorms of the Libyan desert. Of them it is said " The prevailing surface wind in the desert in summer is north-westerly, occasionally fresh to strong, and this causes sandstorms or duststorms mainly at airfields where vehicles have churned up ground to the north-west. . . . These sandstorms viewed from the air present a patchy appearance with quite large areas free from rising sand and there is usually no difficulty in aircraft finding a landing ground suitable for landing provided they have a reserve of petrol and suitable Regional Control facilities are available. Also sandstorms of this type are relatively easy to forecast. They always die down about half an hour before sunset (when the wind drops) and visibility improves to moderate or good."

Though it seldom reduces visibility below 1,000 yd. the harmattan haze of tropical Africa is of importance since it is persistent, often lasting for 3 or 4 days at a time, is of great depth, 8,000 or 10,000 ft., and may at times reduce visibility to 500 yd. The visibility from an aircraft is invariably worse than along the ground. Harmattan is due to very fine dust raised off the desert far away.

§ 9. RAIN AND SNOW

Heavy rain and snow seriously affect visibility. The degree is dependent on the size of drops or flakes and the number in the air. So no direct correlations can be expected between rate of rainfall (or snowfall) and reduction in visibility. Petterssen[3] gives a table from which the following is generalised.

Very light snow reduces visibility to between 2,000 and 1,000 yd., moderate snow brings it down to under 1,000 yd., heavy snow to less than 500 yd. and very heavy snow to less than 100 yd.

Light and moderate rain impairs visibility little. Heavy rain reduces it below 4,000 yd., very heavy rain below 1,000 yd., while in the tropics very heavy rain can reduce it to less than 500 yd. and sometimes to as low as 50 yd.

In weather which gives drizzle or light rain, falling from cloud with a low base, there are often sufficient minute water drops suspended in the air to reduce visibility very materially, but it would seem that the actual drizzle drops have little effect on visibility, since even if the drizzle stops the visibility does not improve unless there is a change in the air mass.

§ 10. DIURNAL VARIATION OF VISIBILITY

It is well known that fogs are in general more likely to occur at night and in the early morning than during the afternoon. This is largely due to the tendency for the air near the surface to warm up during the day-time and for the greater turbulence thereby engendered to stir the foggy air into the drier air above until it becomes dissipated.

To illustrate the degree of the diurnal variation of fog a table is given of the frequencies of the occurrence of visibility less than 1,100 yd. for certain stations in the British Isles.

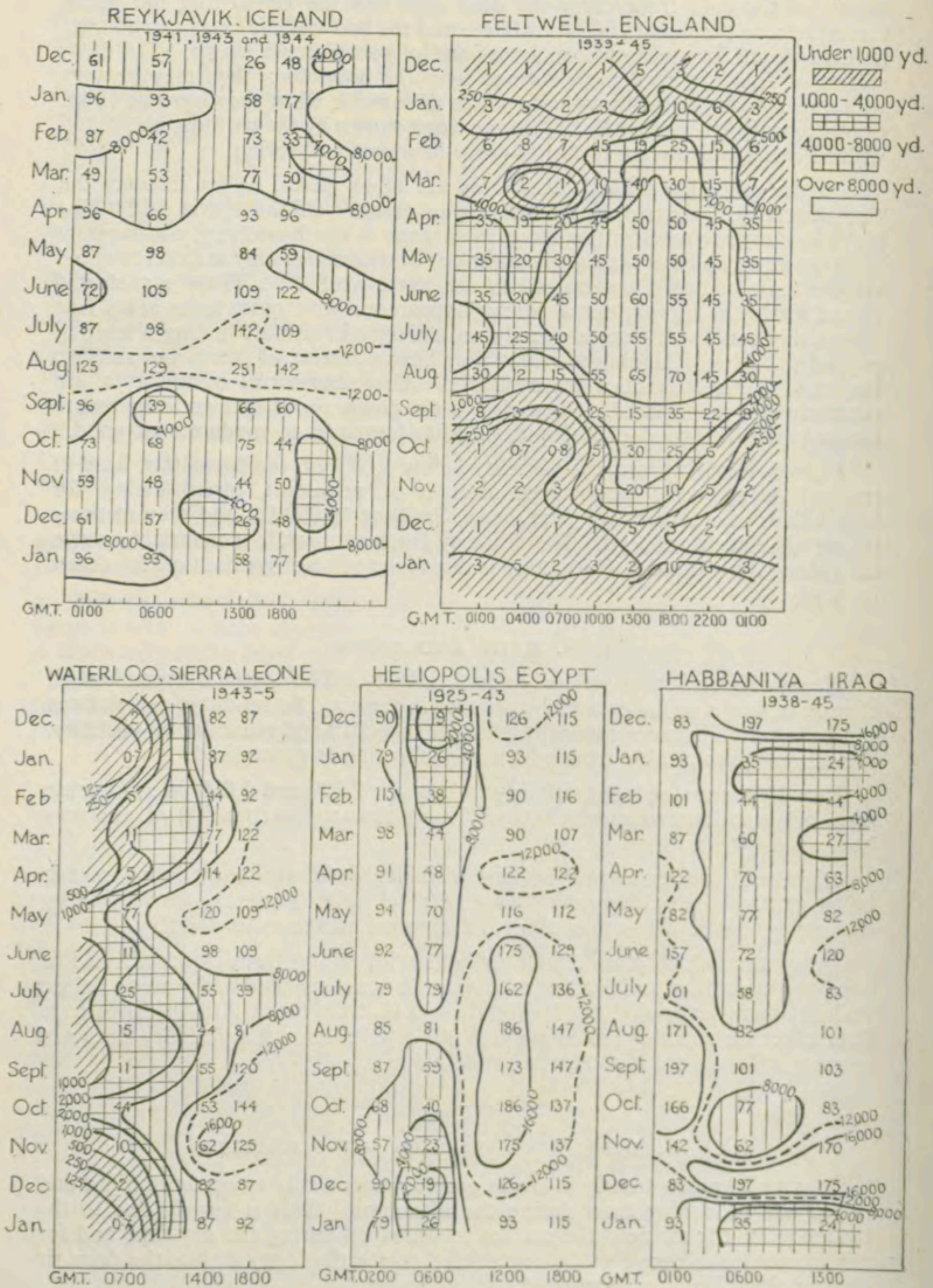

FIG. 2.—DIURNAL SEASONAL VARIATION OF VISIBILITY

Average distance in hundreds of yards at which an object is visible half the days of the month at different hours

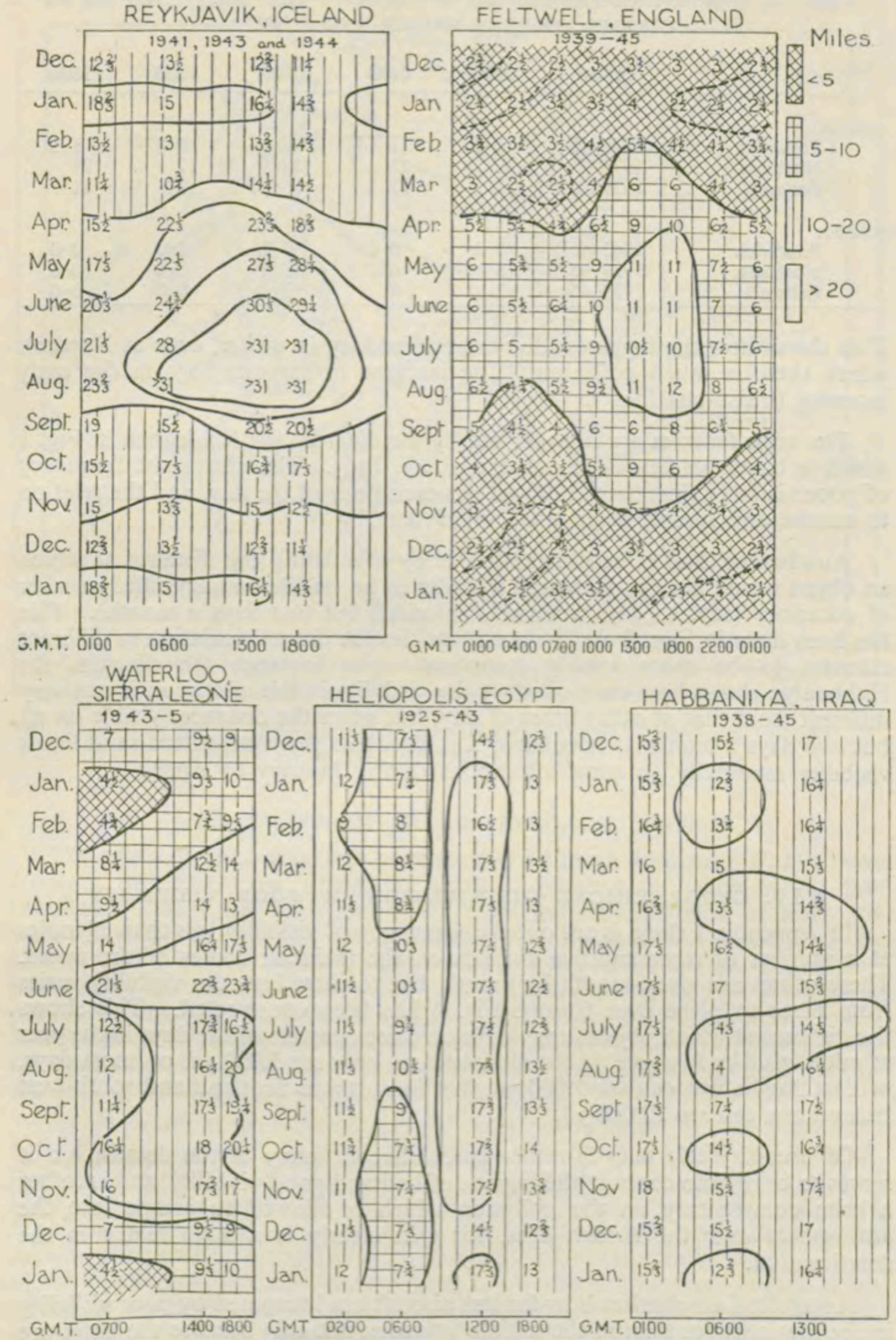

FIG. 3.—DIURNAL SEASONAL VARIATION OF VISIBILITY

Average distance in miles at which an object is visible on all but two days a month at different hours

TABLE V—PERCENTAGE FREQUENCIES OF VISIBILITY LESS THAN 1,100 YD. AT CERTAIN HOURS IN WINTER AND SUMMER

	Period	0100	0400	0700	1300	1800
				per cent.		
WINTER						
Prestwick	1942–45	1·5	1·1	0·4	0·0	1·5
Northolt	1939–45	26	25	26	17	29
Feltwell	1939–45	17	17	16	9	11
SUMMER						
Prestwick	1942–45	0·0	0·4	0·7	0·0	0·0
Northolt	1939–45	3	6	3	0·4	0·6
Feltwell	1939–45	2	4	3	0·0	0·0

This shows how the fogginess decreases at midday in winter, even at Northolt where there is much pollution. The increase in summer fogs in the early morning is also striking.

The same features are brought out by the diagram for Mildenhall in Fig. 1 which is based on figures due to Mr. F. W. Jude. This shows the frequency of poor visibility (less than 2,200 yd.) at each hour of the day, and the relation to sunrise and sunset, based on 5 years' data.

Another method of representation is by calculating the distance at which an object would have to be placed in order to be visibile on a specified number of occasions (say, 15 days a month, or on all but two days a month). This has been done in Figs. 2 and 3 since it enables the diurnal variation in different climates to be more readily compared. For instance the diagram for Habbaniya shows how on most days the visibility in the afternoon is not very different from that at other times of day, but when the distances visible on all but two days a month are examined it is clear that the wind-stirred sand limits visibility materially on some afternoons during January to April.

§ 11. GEOGRAPHICAL DISTRIBUTION OF POOR VISIBILITY

In Appendix I there is set out the frequency of visibility less than 2½ miles at a number of representative airfields on the main air routes of the world. These values are given month by month, but to show how the visibility varies from place to place over Europe Fig. 4 has been constructed. This shows the distance at which objects are visible on three quarters of the days in the year at midday. For instance, in London one can only see 3,000 yd. on most days, in East Anglia one can see 7,000 yd., but in northern Scotland and south-west Ireland one can see 20,000 yd.

Of necessity this map is rather speculative in many of the details, but it serves to bring into contrast the regions of bad and good visibility, and is rather a grim commentary on the pollution which is allowed to escape into the atmosphere over the British Isles, for that clearly is a main factor in the deterioration.

Appendix I emphasises how far less aircraft are hampered by poor visibility in the low latitudes than in the middle latitudes, not only because the latter are more developed industrially, but also because the strength of the sun in low latitudes promotes vigorous convection on most days which is sufficient to dissipate the pollution into the upper atmosphere and away from the surface layers.

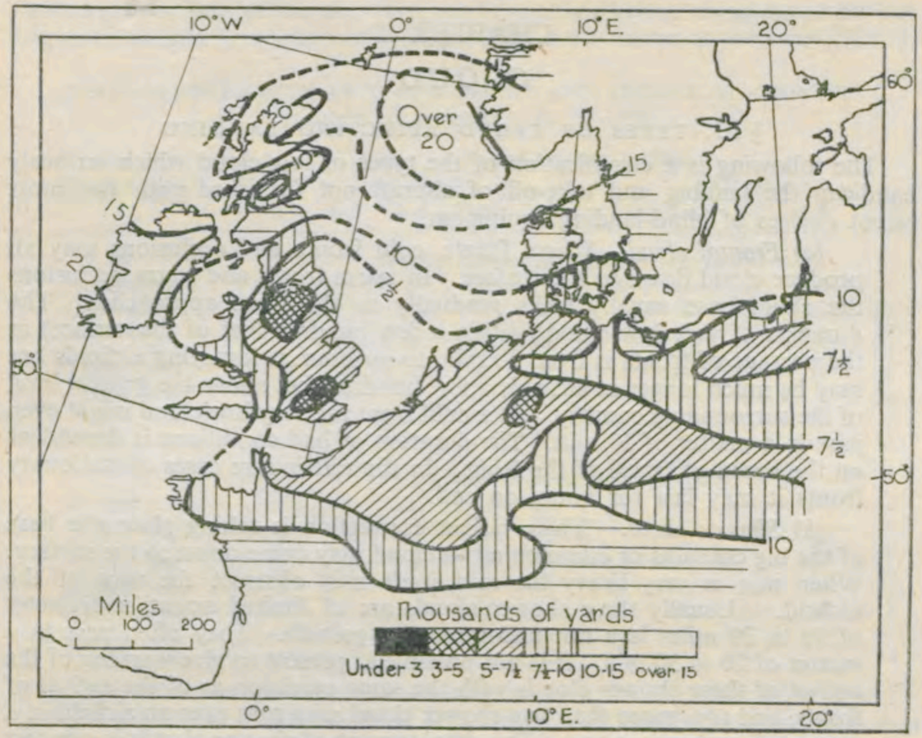

FIG. 4.—DISTANCE IN THOUSANDS OF YARDS OF A POINT VISIBLE AT MIDDAY ON THREE QUARTERS OF THE DAYS OF THE YEAR

§ 12. SITING OF BLIND-APPROACH SYSTEMS

The siting of blind-approach systems may be much influenced by the most frequent direction from which the wind is blowing on occasions of low visibility. This is not the same as the most frequent direction of wind. A meteorologist with experience of conditions at the airfield in question may be able to give a correct opinion as to which runway should be chosen, but in many cases it is necessary to conduct a statistical examination for the express purpose of selecting the suitable runway. When detailed examination is made it is found that in some cases at any rate there is little to choose between siting the blind-approach system on one runway rather than another because the bad visibility is so often associated with light winds.

As an example may be quoted an examination made of the Mildenhall airfield data for a year. Suppose the limits of conditions are as low as 1,100 yd. visibility and 600 ft. cloud height and a cross runway component of wind of 13 kt. (15 m.p.h.) and a tail wind not exceeding 4½ kt. (5 m.p.h.). The wind directions which most often bring bad conditions are SW. and NE. but if a runway were sited in a south-east direction it could take all the blind landings except 14 per cent., whereas if it were sited in a south-west or north-east direction all but 25 per cent. and 21 per cent. respectively could be accepted. Because of the light winds the south-east runway can take a considerable proportion of the bad weather approach with both SW. and NE. winds.

CHAPTER II

CLOUD

§ 13. TYPES OF CLOUD AFFECTING LANDING

The following is a classification of the types of low cloud which seriously handicap the landing and take-off of aircraft not furnished with the most recent devices of blind-landing equipment.

(*a*) *Frontal cloud.*—Warm fronts, cold fronts and occlusions may all produce cloud down to the surface. In warm fronts and warm occlusions the cloud base usually sinks gradually as the front approaches. The duration of very low cloud (within a few hundred feet of the surface) at the passage of fronts is from 30 min. to an hour at low-lying airfields but may be much longer at airfields a few hundred feet above the general level of the surrounding country. At a cold front the very low cloud might even pass in a matter of 10 min. The duration of bad conditions is dependent on the speed of travel of the front. In the rather rare cases of stationary fronts it may last for hours on end.

(*b*) *Shower cloud.*—When violent convection is taking place the base of the big cumulus or cumulonimbus cloud may come down to the surface. When rain is very heavy the rain itself may obstruct the view of the airfield. Usually these shower clouds are of limited extent, a diameter of 10 to 20 miles is a not uncommon magnitude. They often pass in a matter of 20 to 30 min. It is not possible at present to give warning of the arrival of these shower clouds with the same precision as of the arrival of fronts, and too, more than one shower cloud may pass over an airfield in a matter of an hour or two. The development of shower clouds is greatest in the monsoonal rains of the intertropical belt. There the low cloud and heavy rain may persist for hours on end. In cold regions when the showers are snow instead of rain the visibility in the showers is likely to be nil. These cumulonimbus clouds can completely close an airfield for periods up to an hour, for instance during winter they occur fairly regularly in north Scotland (Wick) and seriously interfere with the use of the airfield.

(*c*) *Stratiform cloud.*—This often occurs over wide areas as a level sheet of stratocumulus cloud with a base at about 2,000 ft. above the general level of the ground (or sea). Sometimes when the humidity of the air is great the base is much lower (as in the haars of the east coast of the British Isles) and then the very low cloud is most persistent.

These three main types of obstructive cloud are the same the world over, though they vary in importance from place to place according to the characteristics of the air streams in which any place lies.

Tables are available for many places which give the frequency of occurrence of the bases of the clouds within certain limits laid down internationally. Tables are also available giving the frequency with which low cloud covers various amounts of sky and not infrequently tables showing the heights of bases when the sky is 9 or 10 tenths covered.

In the American service the ceiling of the cloud is defined to be the lowest height at which 5 tenths of the sky appears to be covered, e.g. if there were 3 tenths of sky covered at 2,500 ft. and 2 tenths at 500 ft. the sky would be said to be ceiling 2,500 ft. In the British service the frequency of the height of the main cloud layer may be given, but there are also available statistics of the height of the base of lowest cloud.

To show the sort of distribution of cloud height and amount Table VI is given which shows for Croydon the frequency with which low cloud occupied

various proportions of the sky when the base of the lowest cloud lay at certain heights in summer and winter at 0100 and 1300 G.M.T. based on the years 1935–9.

TABLE VI—FREQUENCY OF CLOUD HEIGHT AND AMOUNT AT CROYDON
Number of occasions in 5 years

Cloud height	Cloud amount (tenths) 0100 G.M.T.					1300 G.M.T.				
	0	1–3	4–6	7, 8	9, 10	0	1–3	4–6	7,8	9,10
ft.	Winter (December, January, February)									
No low cloud	135	—	—	—	—	50	—	—	—	—
Over 3,000	—	13	7	8	34	—	33	21	12	23
3,000–2,000	—	11	6	8	31	—	31	18	21	29
2,000–1,000	—	12	9	12	75	—	8	19	25	63
1,000– 600	—	2	—	4	45	—	—	4	9	38
600– 300	—	—	—	—	23	—	—	—	1	24
300– 150	—	—	—	1	5	—	—	—	—	7
Under 150	—	—	—	—	10	—	—	—	—	15
	Summer (June, July, August)									
No low cloud	236	—	—	—	—	32	—	—	—	—
Over 3,000	—	32	17	7	20	—	77	110	64	34
3,000–2,000	—	5	6	8	22	—	9	15	35	26
2,000–1,000	—	12	6	8	37	—	2	6	14	16
1,000– 600	—	2	2	5	22	—	—	—	5	12
600– 300	—	—	—	—	9	—	—	—	—	3
300– 150	—	—	—	1	1	—	—	—	—	—
Under 150	—	—	—	—	2	—	—	—	—	—

Such a table as this however is of necessity very limited in its scope ; it is not necessarily typical of other airfields.

In Appendix II there is a table of the frequencies of cloud base below 1,000 ft. at a number of the principal airfields of the world. This shows these frequencies differ widely from place to place and season to season.

§ 14. EFFECTS OF TOPOGRAPHY ON LOW CLOUD

The effects of topography on cloud are great; they may be classified as follows :—

(*a*) Effect of small elevations (hills of a few hundred feet).

(*b*) Effect of mountains either isolated or in ranges.

(*c*) Effect of a coast line with on-shore winds.

If a cloudy damp air current strikes a hill or mountain mass some of the air may find a path round the obstacle, some may surmount it. If the hill is low most of the air goes over the top and down the other side. In ascending it may cool (by expansion) sufficiently for more cloud to form, but in descending again on the other side the air is once more warmed (by compression) and the additional cloud is reabsorbed and there is still as much cloud as before the obstacle was encountered and no more. But some of the cloud drops may have become sufficiently large to have fallen out as rain on the hill slope (orographic rain). By that much will the water in the air have been reduced, and in consequence the cloud will be found to be less in amount and very probably with a higher base on the lee side of the hill.

If however the hill mass is sufficiently high (and of a suitable shape) some of the air moves laterally along the base of the hill and so does not pass over the top. The air which passes over the top is then drawn from the upper part of the impinging current, and on passing over the obstacle this air tends to descend to a level below that from which it started. In consequence it is compressed and warmed adiabatically and any cloud in it tends to dissipate. If the two effects of orographic rain and adiabatic warming are combined the resulting clearance of cloud due to " foehn effect " may be very great.

(*a*) *Effect of small elevations*.—Over country which is devoid of major topographic features the base of a cloud sheet does not usually vary in absolute height* so that in such country there is more flying room between the cloud base and ground level over a low-lying airfield than over one at slightly greater elevation (e.g. on a small plateau). In some meteorological conditions however when the air at all heights is very nearly saturated the slight lifting of the air which occurs in passing over a rise of even 200 ft. may cause condensation at a lower height above sea level so that there is a definite dip in the cloud base over even the smaller hills. This effect in a more exaggerated form makes a tendency for cloud to form over the bigger hills when there are no clouds at all at that level over flatter areas surrounding them. This latter effect leads to an enhanced danger due to isolated hills in the neighbourhood of an airfield ; an instance of such is the Wrekin which during northerly winds may induce its own cloud cap when the sky over Atcham airfield is clear. Pilots coming in at night to land may find themselves unexpectedly enveloped in cloud just when they are losing height and may strike the hill before realising what has occurred. An isolated hill is therefore a more serious obstacle at an airfield site when it lies in a current which is likely to be moist. Westerly winds are not likely to produce isolated cloud over the Wrekin because these winds have passed over the Welsh Mountains and in consequence are unlikely to be sufficiently moist.

To show the effect of elevation on the observed cloud heights figures may be quoted for Bristol, Colerne, Hullavington, Lyneham and Membury. If we calculate the frequency of heights of cloud bases above station level and then deduce by proportion the frequency of cloud bases above sea level we get the following table for the period October 1943 to March 1944 and April to September 1944.

TABLE VII—PERCENTAGE FREQUENCY OF HEIGHTS OF CLOUD BASES BELOW 2,000 FT. ABOVE MEAN SEA LEVEL

Station	Height	Distance from Bristol	Frequency of cloud amounts 0100		Frequency of cloud amounts 1300	
			All amounts	9 and 10 tenths	All amounts	9 and 10 tenths
	ft.	miles	*per cent.*			
			Winter (October 1943 to March 1944)			
Bristol	209	—	26	18	31	19
Colerne	577	13	30	27	31	24
Hullavington	320	21	30	4(?)	28	3(?)
Lyneham	455	27	26	22	33	24
Membury	668	44	—	—	—	—
			Summer (April to September 1944)			
Bristol	209	—	21	10	26	13
Colerne	577	13	28	22	24	16
Hullavington	320	21	25	14	20	9
Lyneham	455	27	25	19	24	9
Membury	668	44	33	22	31	16

* This is generally true of flat country of limited extent. Over a large area of fairly uniformly sloping ground there is a tendency for the cloud base to maintain a more or less constant height above the general level of the ground, for example in the United States where the general level of ground slopes upwards from east to west, from the Mississippi to the Great Plains, the general level of the cloud bases usually also slopes upwards from east to west in conformity.

This brings out clearly how the sheets of low cloud tend to be much more common over the hills in winter and during summer nights. Rather similar figures are found for heights of 1,000 ft. and 3,000 ft. above sea level. The contrast between the night observations and those in early afternoon is striking. During the night the cloud tends to be low more often over the high ground than over the Bristol plain ; during the day in summer it tends to be low less often over the general mass of high ground.

(*b*) *Effect of mountains*.—The effect of isolated mountains has to be distinguished from that of chains of mountains orientated at right angles to the main stream. In the former case some of the air can flow around the flanks of the mountain and thereby pass it without the necessity of rising. In the case of a mountain range the air has to rise in crossing, and hence, given a suitable distribution of water vapour, condensation takes place and produces cloud at a low altitude.

On the lee side of a big hill mass such as the Cambrian Mountains, the Pennines or the Grampians the foehn effect produces a definite breaking and lifting of the cloud as is seen from the discussion below. Two stations, Penrhos and Ternhill, were examined for the year 1944 on all occasions when (*a*) the geostrophic wind was between SW. and NW. and (*b*) when it was between NE. and SE. Penrhos is on the coast north of Cardigan Bay and south-west of Snowdonia, Ternhill is north-east of Shrewsbury ; so these two stations could be taken as showing the clearing effect due to the Welsh Mountains. The amounts and heights of base of low cloud reported at each station were tabulated for each occasion. The results have been set out in Table VIII which shows the frequencies with which low cloud amounts at the two places fell into certain categories when the base of the lowest cloud was below 2,000 ft.

TABLE VIII—PERCENTAGE FREQUENCIES OF LOW CLOUD WITH BASE BELOW 2,000 FT. FROM OBSERVATIONS MADE SIMULTANEOUSLY AT PENRHOS AND TERNHILL IN 1944

Frequency of low cloud at Ternhill	Frequency of low cloud at Penrhos: Nil	1–3 tenths	4–6 tenths	7–9 tenths	10 tenths	Total
tenths	*per cent.*					
	(*a*) SW. to NW. airflow (607 observations)					
Nil	26	2	11	18	5	62
1–3	2	0·2	0·7	0·7	—	4
4–6	4	0·6	2	3	—	9
7–9	8	1	2	6	0·6	18
10	3	0·7	0·7	2	1	7
Total	43	5	16	29	7	100
	(*b*) NE. to SE. airflow (186 observations)					
Nil	54	2	1	1	—	58
1–3	2	0·5	—	—	—	3
4–6	4	—	1	—	—	5
7–9	8	1	1	2	0·5	12
10	15	3	2	2	—	22
Total	83	7	5	5	0·5	100

When the wind is easterly skies are clear below 2,000 ft. over both stations more often than when there are westerlies, but if there is cloud in an easterly stream it is generally confined to the eastern side of the Cambrian Mountains ; at Penrhos there are 90 per cent. of days with less than 4 tenths of low cloud below 2,000 ft. In contrast when winds are westerly clear skies below 2,000 ft. are much less common at Penrhos, but on a third of the days of westerly winds the sky was half cloudy at Penrhos and was quite clear at Ternhill. Indeed a short table can be made showing broadly the frequency with which the very low cloud at Penrhos was more than that at Ternhill by at least 5 tenths and *vice versa* as is done below.

TABLE IX—PERCENTAGE FREQUENCY WITH WHICH LOW CLOUD AT PENRHOS EXCEEDED THAT AT TERNHILL BY 5 TENTHS OR MORE (AND *vice versa*)

	With westerly winds	With easterly winds
	per cent.	
Ternhill more than Penrhos by 5 tenths	17	33
Penrhos more than Ternhill by 5 tenths	35	2
Cloud less than 4 tenths at both places	30	59

The mass of the Cambrian Mountains and Grampians is sufficient to force most of the impinging air to flow over the top, but on the flanks some flows round, an effect which in these cases is more important from the point of view of wind than of cloud.

This foehn effect is apparent in many parts of the world. The clearance of skies over the Po Valley with general northerly air streams over the Alps is an example on the grandest scale. To quote others, the Norwegian Mountains give a notable clearance of skies over Oslo in winter with north-westerly winds, the Ardennes give a clearance over the Rhine with westerly winds, and the Montagne d'Arree and the Montagnes Noires in Brittany give an appreciable lifting to the cloud over Rennes, so that in thick south-westerly weather aircraft can be sure of creeping across the base of the Brittany Peninsula through the gap between.

The citation of cases might be extended indefinitely. From the point of view of siting airfields it is probably the features of 500 to 2,000 ft. which play the most important role. Hills less than 500 ft. are usually not high enough to divert the wind flow so as to create a big enough foehn effect. Features of greater height than 2,000 ft. shield so large an area that the whole climate of the region is affected. For example in the case of the Po Valley this modification may give rise to greater problems than that of low cloud itself.

As some guide to the distance to which the clearance of low cloud by foehn effect extends there may be quoted some figures from German authorities referred to by Morgans[4] which give the horizontal distance to leeward of the mountain at which a very notable clearance of cloud occurs.

TABLE X—HORIZONTAL " DISTANCE OF INFLUENCE " OF CERTAIN MOUNTAINS

Mountain	Height		Horizontal distance of influence in the lee	
	m.	ft.	Km.	miles
Tautoberger Wald	350	1,150	10	6
Taunus	880	2,900	12 to 13	8
Thuringer Wald	900	2,950	13	8
Harz	1,100	3,600	17	11
Schwarzwald	1,500	5,000	28 to 29	18
Kalkalpon	2,500	8,200	55	35
Alps	2,500	8,200	55	35

To reduce these to a formula Georgii (see Bibliography No. 4, p. 67) gave

$$R = H \cos \frac{\alpha}{2}$$

Where R is the horizontal distance of influence, H is the height of the summit above the plains, and α is the slope of the mountain from the foot to the summit.

It is to be noted that the " distance of influence " is the distance to which an almost complete clearance of low cloud extends; at a greater distance the low cloud tends to reform but the very low cloud may well not reform for three or four times the distance given by Georgii's formula, and this certainly seems to be the case both at Prestwick, where the Isle of Arran gives protection from NW. winds, and at Thorney Island, where the downs on the Isle of Wight give protection from south-westerly winds.

The forced ascent on the windward side of a mountain extends back up-wind so that cloud then may be expected to be heavy on that account some miles from the mountain foot, but no data are available to say how far up-wind this effect generally extends.

(*c*) *Effect of coast line on very low cloud with on-shore winds*.—If an unstable air current (i.e. one in which the lapse rate of temperature is high and there are probably many cumulus clouds) flows on to a coast line the additional friction and possibly the additional heating sets up a large increase in cloudiness and often the stirring of the air leads to a very substantial decrease in the height of the cloud base. For this reason an airfield near a coast on to which polar currents are liable to blow is likely to be handicapped to some extent, though the proximity of the sea may cause it to be freer from radiation fog than a place further inland.

In the tropics winds off the sea are liable to bring rain and low cloud especially if the coast has mountains backing on to it ; in a pronounced and unstable current, such as the SW. monsoon of the Bay of Bengal, the cloud effects extend back 20 miles from the mountains.

To give an idea of the frequency with which very low cloud bases occur in monsoon conditions Fig. 5 shows the frequency of cloud with base at less

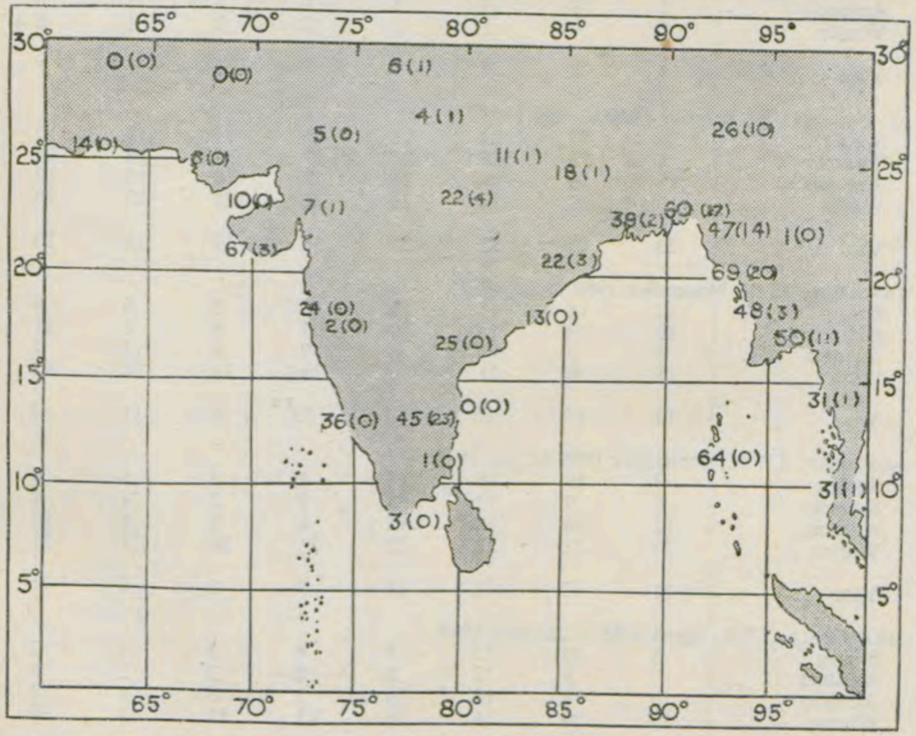

FIG. 5.—PERCENTAGE FREQUENCY OF CLOUD BASE BELOW 2,000 FT. DURING JUNE, JULY AND AUGUST

Percentage frequencies below 1,000 ft. are inserted in brackets than 1,000 ft. and 2,000 ft. during the SW. monsoon months, June, July and August, at certain places in India based on morning and afternoon observations.[5] The high frequency of cloud below 1,000 ft. on the coast of Burma is very noteworthy. The frequency on the west coast of India of cloud below 2,000 ft. is generally less than over the west coast of Burma but appreciably higher than on the east coast of India. The high frequency at Bangalore (12° 58′ N. 77° 30′ E.) is due to the station itself being 3,000 ft. above sea level.

§ 15. DIURNAL VARIATION OF LOW-CLOUD FREQUENCY

The diurnal variation of low cloud is illustrated in Table XI by the average percentage frequency of sheets of cloud below 1,000 ft. at Prestwick, St. Eval, Tangmere, Northolt and Mildenhall, the three former representing coastal conditions, Northolt an airfield within the influence of London, and Mildenhall a country site.

TABLE XI—PERCENTAGE FREQUENCY OF OCCURRENCE OF CLOUD SHEETS (9 AND 10 TENTHS) WITH BASES LESS THAN 1,000 FT. ABOVE THE AIRFIELDS AT VARIOUS STATIONS AT DIFFERENT HOURS

Hour (G.M.T.)	0100	0400	0700	1000	1300	1600	1800	2200
PRESTWICK, 30 ft., August 1942 to July 1945								
Spring ..	0·4	1	0·7	1	1	2	2	0·7
Summer ..	0·7	1	2	1	1	1	0	1
Autumn ..	2	3	3	5	1	3	2	3
Winter.. ..	2	1	1	2	2	2	1	0·4
Year	1	1	2	2	1	2	1	1
ST. EVAL, 345 ft., January 1940 to July 1945								
Spring ..	22	19	23	21	16	16	18	19
Summer ..	23	23	25	24	17	18	16	24
Autumn ..	15	15	19	21	17	18	15	17
Winter.. ..	17	19	19	23	21	23	23	20
Year	20	19	22	22	18	19	18	20
TANGMERE, 53 ft., November 1939 to July 1945								
Spring ..	12	14	15	11	10	3	6	6
Summer ..	10	13	12	9	7	6	8	11
Autumn ..	8	9	10	8	9	4	11	4
Winter.. ..	18	20	21	16	19	18	20	13
Year	12	14	15	11	12	8	11	8
NORTHOLT, 137 ft., September 1939 to July 1945								
Spring ..	7	10	16	14	4	5	5	6
Summer ..	6	9	12	3	3	2	4	4
Autumn ..	12	14	18	14	8	7	8	10
Winter.. ..	20	22	22	25	21	20	21	21
Year	11	14	17	14	9	8	9	11
MILDENHALL, 15 ft., April 1938 to January 1945								
Spring ..	8	10	12	7	4	3	4	2
Summer ..	7	9	12	8	2	2	2	5
Autumn ..	9	11	13	13	5	5	4	7
Winter.. ..	15	14	16	16	15	11	11	10
Year	10	11	13	11	7	6	5	6

The maximum frequency is in the early morning in every case, the diurnal variation being far more pronounced in summer than in winter. The diurnal variation over land is more marked than on the coast.

The early morning cloud sheets in summer at Mildenhall and Northolt are very striking. Clearance is due to the lifting of the condensation level as the sun warms the earth and air and to the breaking up and dispersing of the cloud by convection.

CHAPTER III

FLYING-FITNESS FIGURES

§ 16. GENERAL

The extraneous physical limitations in the general survey for siting an airfield vary widely according to the type of airfield which is required and the existing communication with the centres of population and other factors. Hence the " district " of the general survey may be very severely restricted in the case of an airfield for local flying or may extend over a whole country if the airfield is to be a bad-weather alternative to a main trunk air terminal ; but whether the district is confined or extensive the meteorological factors which effect the siting of the airfield are the liabilities (i) to bad visibility, (ii) to low cloud, (iii) to strong winds, and (iv) to bumpiness at take-off and landing. These factors are not, however, independent of one another, and for the ideal survey it would be necessary not merely to know the frequency with which poor visibility would limit operations at every site in the district and also the

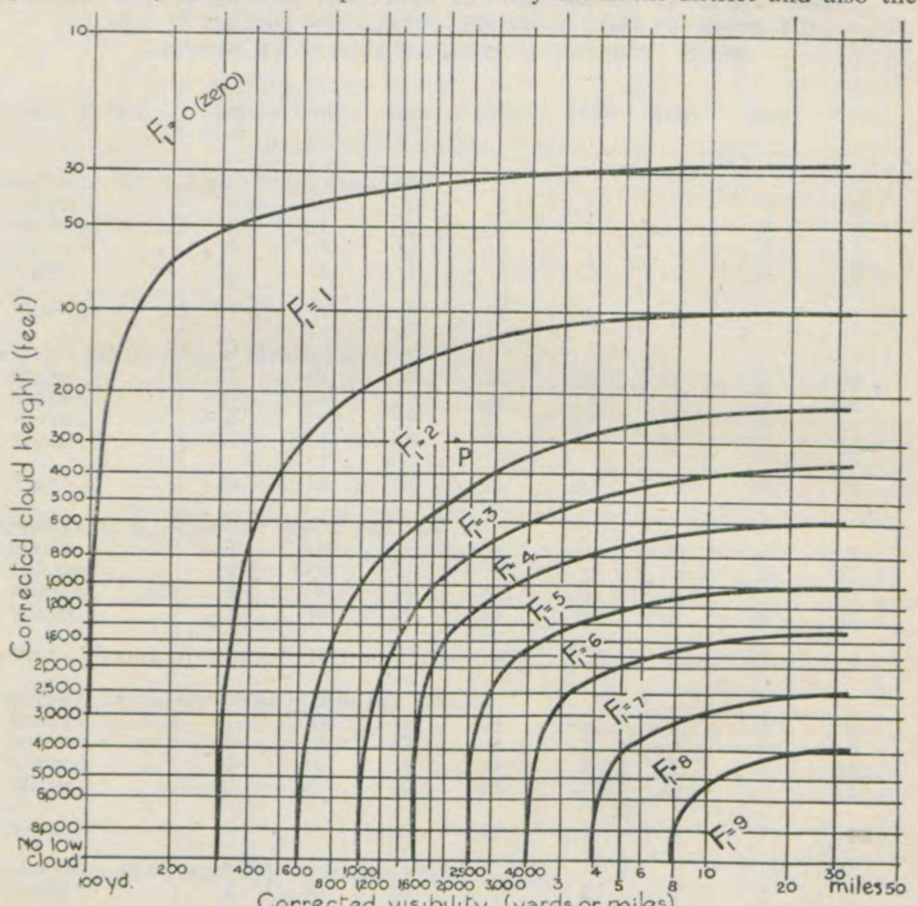

FIG. 6.—DIAGRAM FOR OBTAINING INITIAL LANDING-FITNESS NUMBER F_1 FROM VISIBILITY AND CLOUD HEIGHT

Before use with this diagram cloud height is corrected for obstruction height and visibility for precipitation. The final fitness number F_n is obtained from F_1 by correcting for cloud amount and wind. Example : corrected visibility 2,200 yd. and corrected cloud height 300 ft. gives point P where fitness number (F_1) is 2

frequency with which low cloud would hamper landings, but in what proportion of time would a combination of low cloud and poor visibility and strong wind prevent operation of the particular aircraft for which the airfield was being designed.

A step towards this ideal has been taken in the formation of fitness figures, designed by E. Gold, and their summarization, though the survey made with them only extends to the British Isles in detail and to certain regions under British control.

The use of these fitness figures greatly facilitated the mass diversion schemes during the war, when information was required rapidly, graphically and simultaneously of the state of many airfields. The meteorological factors were graded into ten categories. In assessing the appropriate visibility the effect of rain and snow was taken into account, and in assessing the cloud height the obstructions on and near the airfield were allowed for. This gave corrected visibility and cloud-height values which were used in combination to read the appropriate fitness figure off the diagram shown at Fig. 6. Further refinements are added to allow for state of runways and the wind speed and direction in relation to them, the resultant value being known as F_n.

These fitness figures, F_n, have been calculated for many airfields in the British Isles, and as a result of the calculation of frequencies a general survey has been possible covering three years' observations. To do this the frequencies of fitness figures 0 to 2 and 6 to 9 have been calculated, these fitness figures (shown in Fig. 6) are termed " fitness red " and " fitness green " respectively, as they correspond broadly to conditions in which no aircraft can land without special aids and to conditions in which any aircraft can land without hindrance.

The results are shown in Figs. 7 and 8 which represent the annual frequency of fitness red and fitness green. In these diagrams the values shown in circles are percentage frequencies of all daylight observations, while the numbers by the side of the circles are the station numbers of the observing stations. Over much of England the stations are so crowded that it is quite impossible to represent them on this diagram, but specimen stations have been plotted and dotted lines have been drawn roughly enclosing areas where frequencies are high and low.

A drawback must be noted, however, to the fitness figures as devised for the special needs of the controllers. The obstruction heights used were assessed in relation to the type of aircraft using the airfield. This had some curious effects in cases where a high hill was in the neighbourhood and was an obstruction to one type of machine but not to another.

§ 17. GEOGRAPHICAL DISTRIBUTION IN THE BRITISH ISLES

The outstanding feature of the fitness maps is the low frequency of bad conditions in certain specific areas :—

(i) Around the Moray Firth.
(ii) In the Prestwick–Ayr region.
(iii) On the shores of Lough Foyle.
(iv) At East Fortune.
(v) On the shores of Lough Neagh.
(vi) At Felixstowe.
(vii) At Jurby.
(viii) At Thorney Island.
(ix) On the shores of the Solway Firth though to a lesser degree.

All these sites are on a coast (either of the sea or a lake) and with the exception of Felixstowe have hills to the back of them. The physical cause of their good conditions is clearly that the sea tends to keep the temperature up during autumn and winter nights when fogs form inland, and if any fog does form early in the night the cooled air on the neighbouring hills tends to slide down as a katabatic wind. This keeps the air in motion and drifts any fog away.

The first three of the regions have additional advantages. At Lossiemouth, Kinloss and Tain cloud is usually comparatively high because the air from any direction except between north and east has had to come over mountains and consequently has been cleared by the foehn effect. At Prestwick and Ayr the Atlantic air has not had to traverse such high mountains except when it comes

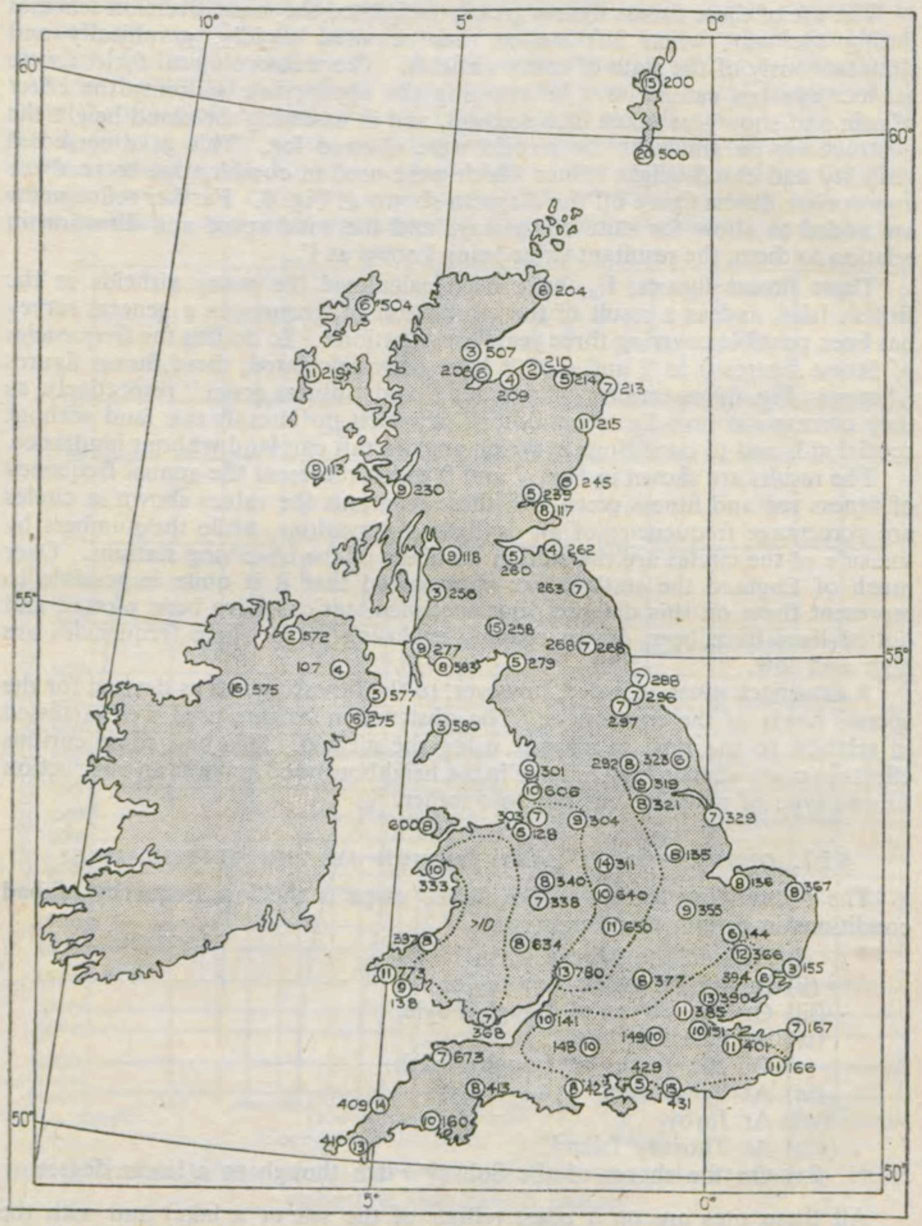

FIG. 7.—ANNUAL PERCENTAGE FREQUENCY OF DAY-TIME FITNESS RED

The figures inside the circles give percentage frequency of red fitness, those by the side are index numbers of the stations prior to 1949

from the north, and the hills of Kintyre and Arran give protection from the west and north-west and to a great extent the mountains of Antrim from the south-west. The Southern Uplands are a guard to the south, south-east and east, and very bad weather can really only get over the airfield at Prestwick during disturbances which give rise to winds over the North Channel and the Firth of Clyde. At Limavady and Ballykelly mountains lie on every side and the water in the cloud is deposited on them sufficiently to prevent very low cloud bases.

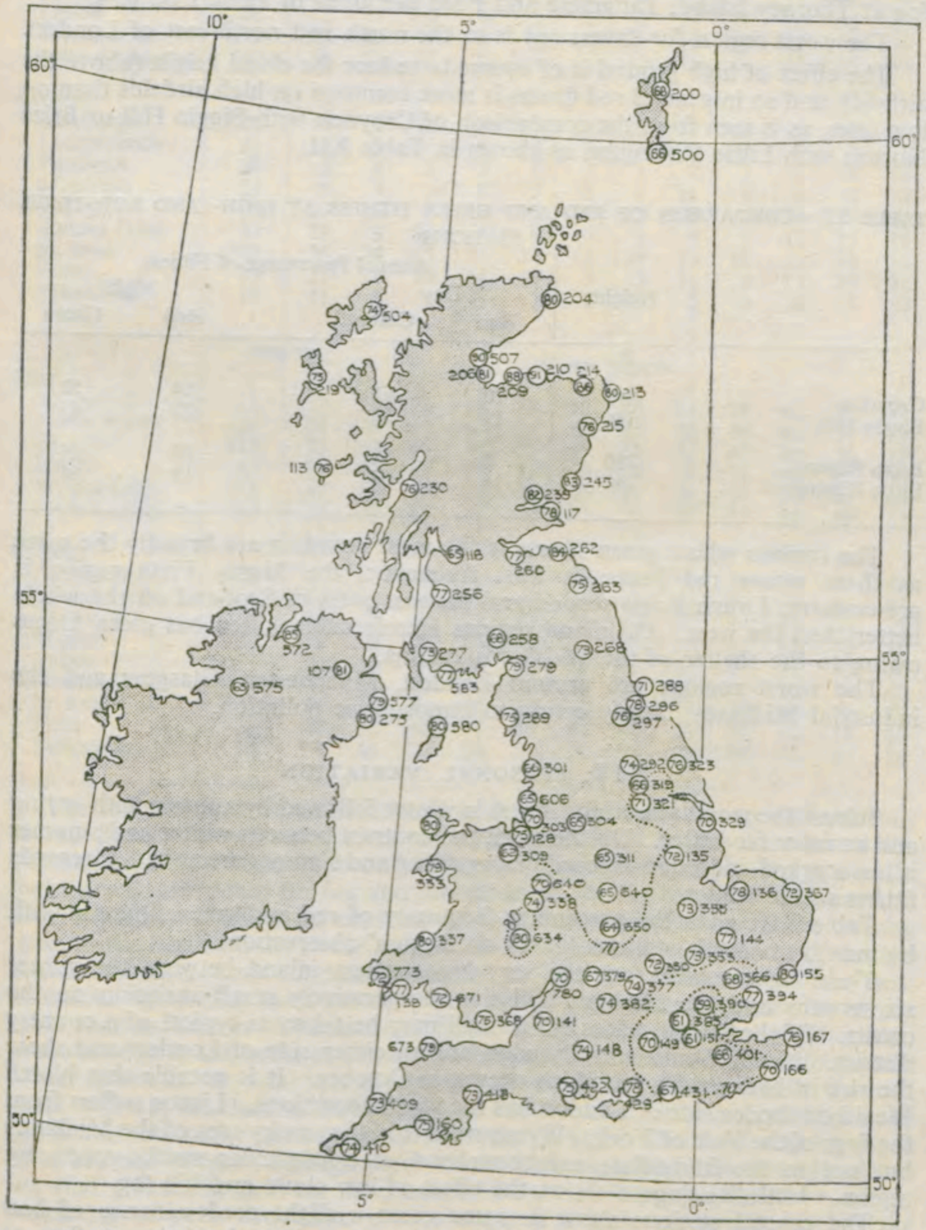

FIG. 8.—ANNUAL PERCENTAGE FREQUENCY OF DAY-TIME FITNESS GREEN

The figures inside the circles give the percentage frequency of green fitness, those by the side are index numbers of the stations prior to 1949

Since the south-east of England has generally so few good airfields (from the meteorological point of view) it is worth noting how Thorney Island stands out. The comparatively high values for red frequency at Tangmere and Ford are due largely to the obstruction height at those places taking into account the proximity of the Downs. At all three airfields, but particularly at Thorney Island, the katabatic wind from the Downs at the back is known to keep these airfields free from fog and the protection afforded by the high ground of the Isle of Wight reduces the frequency of low cloud bases. The frequencies of fog at Thorney Island, Tangmere and Ford are given in Table I on p. 4.

The worst region for fitness red is to the north and north-east of London.

The effect of high ground is of course to reduce the cloud height (above the airfield), and so in general red fitness is more common on high airfields than on low ones, as is seen from the comparison of Croydon with Biggin Hill or Brize Norton with Little Rissington as shown in Table XII.

TABLE XII—COMPARISON OF RED AND GREEN FITNESS AT HIGH- AND LOW-LEVEL STATIONS

	Height	Annual Percentage of Fitness			
		Day		Night	
		Red	Green	Red	Green
	ft.	per cent.			
Croydon	217	10	61	14	52
Biggin Hill	556	19	55	22	49
Brize Norton.. ..	280	8	72	10	66
Little Rissington ..	740	16	67	19	64

The regions where green fitness is the most common are broadly the same as those where red fitness is least frequent : the Moray Firth region is pre-eminent, Lough Foyle second and the east coast of Scotland on the whole better than the west. Of inland regions Herefordshire often has green fitness owing to the shelter of the Welsh Mountains.

The worst regions are around London, Manchester, Glasgow and the industrial Midlands, clearly owing to atmospheric pollution.

§18. SEASONAL VARIATION

Inland the worst season for fitness is winter followed by autumn with spring and summer far better. On the coast the contrast between winter and summer is less marked, indeed in exposed places spring and summer are as bad as regards fitness as the winter.

Table XIII gives the percentage frequency of red and green fitness month by month at certain stations (based on 3-years' observation).

These figures bring out the very big contrast inland between the winter six months and the summer, and the comparatively small variation on the coasts. Of the inland places Mildenhall may be taken as typical of a country district. North Weald and Croydon are on either side of London and show the rise in bad conditions which occurs in October. It is notable that North Weald on the lee side of London has the worst conditions. Linton suffers from the fogs of the Vale of York. Wymeswold is in the smoky area of the Midlands but not in the immediate neighbourhood of a particular smoke-producing region. Little Rissington shows the effect of low cloud and hill fog.

The coastal stations show in some cases a slight predominance of bad conditions in spring and summer, but even a few miles inland the sea fogs of summer tend to dissipate.

TABLE XIII—PERCENTAGE FREQUENCY OF FITNESS RED AND GREEN AT CERTAIN PLACES

	Height	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	ft.												
		Red Fitness											
Inland													
Mildenhall	15	16	8	7	4	1	1	3	6	7	14	15	18
North Weald	32	31	20	12	8	3	4	6	8	11	24	25	34
Croydon	217	21	14	11	6	8	2	4	4	7	23	23	29
Linton	46	22	7	5	8	5	1	3	7	7	13	12	21
Wymeswold	272	23	12	9	4	4	1	2	9	10	15	19	26
Little Rissington	740	35	21	12	11	8	7	12	15	10	25	25	33
Coastal													
Sumburgh	20	19	21	15	26	19	29	26	25	19	19	10	25
Lossiemouth	21	3	1	0·7	3	7	3	5	2	2	3	3	1
Prestwick	30	3	4	2	3	1	2	1	2	3	5	4	4
Montrose	22	8	3	2	8	7	5	7	11	8	6	4	4
Valley	32	10	11	9	12	8	6	9	9	6	5	7	10
Squires Gate	33	21	9	10	7	4	4	4	5	6	12	15	18
St. Eval	345	16	24	13	16	14	15	19	16	12	12	12	11
Ford	23	27	25	14	14	15	9	13	15	9	17	13	21
Felixstowe	10	11	7	4	3	2	2	0·7	2	2	8	7	10
		Green Fitness											
Inland													
Mildenhall	15	57	71	76	84	88	90	86	84	76	65	53	52
North Weald	32	24	38	42	60	74	62	75	70	66	42	30	19
Croydon	217	31	42	49	74	70	91	81	82	67	42	28	25
Linton	46	56	71	79	74	83	90	84	73	76	61	65	55
Wymeswold	272	43	58	63	79	83	90	87	78	74	58	41	44
Little Rissington	740	44	58	69	77	80	83	70	73	79	56	50	43
Coastal													
Sumburgh	20	62	61	70	56	68	59	61	64	71	69	69	63
Lossiemouth	21	90	94	96	90	86	91	85	91	93	90	91	93
Prestwick	30	69	77	82	78	84	83	87	77	81	73	74	69
Montrose	22	78	90	88	80	83	87	81	78	81	81	88	78
Valley	32	74	76	74	76	84	85	82	79	81	81	80	70
Squires Gate	33	47	64	61	72	80	81	81	77	73	57	54	46
St. Eval	345	64	65	75	70	73	76	66	71	78	76	75	74
Ford	23	47	55	65	76	69	84	76	72	76	60	56	49
Felixstowe	10	54	66	72	86	89	92	91	88	86	76	65	55

For the year as a whole Sumburgh is the station with the highest frequency of red fitness for which records are available. This is due in part to the obstruction height being high on account of neighbouring hills, but it is clear that there is a tendency for fog and low cloud off the sea to arrive at all seasons with southerly winds. In contrast Lossiemouth and Prestwick are among some of the best stations in the British Isles. There is a slight tendency for the former to have bad conditions blown in during summer from the sea. Montrose and Valley both get some fog and low cloud in summer but hardly more than in winter. Squires Gate however has a decided winter maximum, probably due in the main to the smoke blown up from Manchester during the winter months. St. Eval is a comparatively high-level station on the Cornish coast and receives the low cloud from off the Atlantic with consequential poor conditions on many occasions all the year round. The bad conditions at Ford are due in part to a high obstruction value but also to the low cloud and fog that penetrates in from the English Channel. Felixstowe shows a winter maximum of poor conditions even though it is right on the coast, but the prevailing wind is off shore and in winter it lies within the fringe of the smoke pall of London.

§ 19. DIURNAL VARIATION OF FITNESS

The diurnal variation of red fitness is shown in Table XIV.

TABLE XIV—DIURNAL VARIATION OF RED FITNESS (PERCENTAGE FREQUENCY)

	0100–0300	0400–0600	0700–0900	1000–1200	1300–1500	1600–1800	1900–2100	2200–2400
	per cent.							
	Summer (June, July, August)							
Tiree	12	11	12	9	6	8	9	11
Leuchars ..	15	12	13	8	8	8	11	12
Wymeswold ..	4	6	5	4	1	2	1	3
Mildenhall ..	7	7	4	2	1	2	3	3
Tangmere ..	15	19	16	7	9	10	10	11
St. Eval	21	22	19	15	12	12	16	18
	Winter (December, January, February)							
Tiree	11	9	9	9	9	10	11	11
Leuchars ..	7	8	6	6	6	7	7	8
Wymeswold ..	25	26	22	20	19	16	18	21
Mildenhall ..	18	17	14	12	10	12	14	15
Tangmere ..	24	26	28	24	22	22	19	22
St. Eval	17	17	17	17	16	16	17	18

This brings out how much smaller in winter than in summer is the improvement in fitness during the middle of the day, but it is also notable that at both Tiree and St. Eval, stations where the exposure to the open sea is uninterrupted, the day fitness is better in summer than in winter though the night fitness is less bad in winter than in summer. The big frequency of red fitness at Tangmere is in part due to a high obstruction value.

Similar figures of flying fitness are not available for most of the world, but to give an indication of the effects of change in climate Table XV has been constructed which is precisely comparable with Table XIV.

This shows for a few airfields overseas the frequency of red and green fitness. It brings out clearly how far worse are the conditions in the British Isles than at the overseas airfields. It is true that none of the places in this table is representative of such conditions as are found during the SW. monsoon in India and Burma and west Africa, but it is believed that even there the frequency of bad flying conditions is no greater than in the British Isles in winter.

TABLE XV—PERCENTAGE FREQUENCY OF FITNESS RED AND GREEN AT CERTAIN PLACES

	Height	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	ft.	*per cent.*											
		Red Fitness											
Reykjavik ..	34	5	9	8	6	2	3	6	4	4	4	6	3
Gibraltar ..	53	1	2	0·5	0·4	0·1	0·3	2	5	2	0·5	0·6	2
Rabat Sali ..	248	2	9	3	2	0·9	0·1	1	0·2	3	2	3	0·7
Luqa ..	252	1	1	2	2	0·7	0·7	0·7	0	0·3	0	2	3
Nicosia ..	536	1	0	0	0	1	1	0·5	1	0·5	0	0	0·6
Beirut ..	111	4	1	0·8	1	0·7	0·1	0	0	0	0·1	0	0·3
Lydda ..	131	2	1	1	1	1	0·3	0	0·1	0	0·2	0·4	0·9
Ismailia ..	53	0·5	0·2	1	1	0·5	0·5	0·3	0·2	0·9	0·3	1	4
Aboukir ..	37	1	0·5	1	0·6	0·3	0·5	0	0	0·3	0·3	0·1	1
Heliopolis ..	144	0·2	0·3	0·3	1	0·7	0·5	1	0·7	2	0·3	0·8	2
El Geneina ..	2,641	0	0	1	0	0	0·7	1	3	0·6	0	0	0·2
Mosul ..	732	5	3	1	0·7	0	0	0	0	0	0	2	2
Amman ..	2,549	6	7	3	0·5	0	0	0	0	0·1	0	2	6
Habbaniya ..	145	3	1	1	2	0·9	0·3	0·4	0	0·1	0·1	0·7	0·5
Shaibah ..	60	2	1	0·3	1	5	7	9	4	2	0·7	0·3	0·9
Teheran ..	4,002	3	1	3	0·1	1	0	0	0	0	0	0·3	2

TABLE XV—PERCENTAGE FREQUENCY OF FITNESS RED AND GREEN AT CERTAIN PLACES—*continued*

	Height	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
	ft.	*per cent.*											
		Green Fitness											
Reykjavik ..	34	85	72	72	80	88	86	85	86	76	79	73	80
Gibraltar ..	53	95	94	95	97	97	97	95	94	96	97	94	91
Rabat Sali ..	248	91	80	90	93	95	92	94	89	90	94	91	92
Luqa ..	252	82	93	86	88	95	98	99	99	99	96	86	85
Nicosia ..	536	93	92	97	97	97	99	99	98	99	99	99	95
Beirut ..	111	84	92	93	96	98	100	100	100	100	99	96	95
Lydda ..	131	84	90	94	95	97	99	99	99	100	99	94	92
Ismailia ..	53	97	98	95	97	98	99	98	99	98	99	99	94
Aboukir ..	37	85	92	95	97	98	99	100	100	100	99	98	94
Heliopolis ..	144	97	97	95	94	97	94	91	96	95	98	97	90
El Geneina ..	2,641	100	99	93	99	98	98	96	95	97	99	100	99
Mosul ..	732	81	91	93	97	99	100	99	100	100	99	90	93
Amman ..	2,549	79	81	91	96	100	100	100	100	100	100	92	85
Habbaniya ..	145	90	94	92	96	97	99	96	99	99	98	97	96
Shaibah ..	60	95	98	96	97	93	87	82	90	94	98	98	96
Teheran ..	4,002	91	94	93	99	98	100	100	100	100	100	96	93

As an example of what can occur on the intertropical front (I.T.F.) the figures for Salalah on the south-east coast of Arabia may be quoted. This place lies on the standing position of the I.T.F. in July and August. Whereas in the months October to May or June red fitness is rarely if ever reported and green fitness occurs on almost 100 per cent. of occasions, in July and August 1945 red was reported at more than one observation in three and green only occurred at one observation in five. On the other hand in 1946 red was more rarely reported. These figures are comparable with the worst winter conditions in the British Isles.

§ 20. PROBLEM OF ALTERNATIVES

As an example of the use which may be made of fitness figures, the problem may be posed : " Having chosen the main airfield, which is the best alternative for diversions during bad weather ? ". In deciding the best alternative a number of factors extraneous to meteorology will of course be included, such as the distance from the region to be served by the airfield and the communication facilities, but apart from these fitness figures can be used to make specific an answer which could otherwise be given only vaguely by saying for instance that a coastal airfield and an inland one are much less likely to be simultaneously affected by bad conditions than two inland ones.

In the case of Northolt, a comparison was made for 485 days (between June 4, 1942 and October 1, 1943) with various other airfields. Each 24 hours of the period was divided arbitrarily into " day " (0700 to 1800) and " night " (1900 to 0600). The worst three consecutive hours of the day or night were picked out and the day or night was assessed as good or bad according as those three hours had or had not one hour of fitness 2 or more in the case of Northolt or 3 or more in the case of other airfields. On this basis, Northolt was " bad " on about 7 per cent. of days and 9 per cent. of nights. The other stations were then arranged in order of merit, only considering the days (or nights) when Northolt was " bad " and Table XVI was reached. In the last column is given the percentage frequency of fitness red during the year at each station since these figures can be used as a yardstick to compare the badness and goodness of the different airfields.

TABLE XVI—PERCENTAGE OF DAYS WHEN NORTHOLT WAS " BAD " ON WHICH OTHER STATIONS WERE ALSO " BAD "

	Height	Distance from Northolt	Percentage frequency	Annual percentage frequency of fitness red
	ft.	miles		
Wittering	257	75	70 to 85	10
Blackbushe	320	25		11
Little Rissington.. ..	740	60		17
Manston	155	80	40 to 60	7
Mildenhall	15	65		8
Wattisham	292	75		13
Harwell	384	35		11
Driffield	65	170	30 to 40	7
Marham	80	90		9
Valley	32	200	15 to 30	9
St. Eval	345	210		15
Thorney Island	10	55		6
Leuchars	36	330	10 to 15	9
Silloth	25	250		6
Prestwick	30	320	5	3

This table gives a certain measure of the advantage to be gained by using as an alternative an airfield at a distance, especially if the values are used with the comparative figures of frequency of red fitness and of height above sea level as well as with due regard to the local geographical situations.

As has been said earlier Thorney Island has notable geographical advantages, but, if we leave out of account that station, the categories of the airfields are grouped broadly according to distance, though an increase in height as at Little Rissington put that airfield into a worse category than might have been expected.

From this examination it was further concluded that if all the 9 airfields mentioned within 100 miles of Northolt had been able to receive aircraft diverted from Northolt, then " good " conditions could have been found at one or another of them on 9 days out of 10 when Northolt was closed down, and on 4 nights out of 5. If all the 15 airfields of the list in Table XVI had had facilities to receive the diverted aircraft, then it would always have been possible to find an airfield with " good " conditions.

These results broadly confirm some general meteorological principles which govern the search for alternatives, namely :—

(i) The further the alternative airfield is away from the principal airfield, the less are they both liable to be unfit together. This generalization is true to at least 400 miles in the type of weather conditions which prevail in the British Isles, because those depressions which frequently affect this country are usually about 600 to 1,000 miles in diameter.

(ii) In general, airfields on two opposite sides of a mountain have (simultaneously) very different weather from one another. This is because winds blowing across a mountain mass tend to be cloudy over the windward slopes, though the cloud breaks to leeward.

(iii) The weather at an inland place is often different from that at a seaside place.

Thus the most satisfactory alternatives from the meteorological point of view are those at considerable distance, separated by a mountain mass and one on the coast the other inland.

CHAPTER IV

PRECIPITATION

§ 21. RAINFALL

Apart from its effect on visibility (which is mentioned in §9, p. 11), rainfall in itself is of little importance to the design and maintenance of airfields except when it occurs in torrential falls in short periods. These may be so heavy as to flood the airfield, and the constructional engineer requires to know what drainage capacity he will need. This is purely a question of the amount of rain falling in specific periods ; these data are scanty for most regions of the world.

The question is examined in some detail for the British Isles by Bilham[6] who gives a table for a number of stations showing the frequency in ten years of falls of 0·2 in., 0·4 in. and 1·0 in. in short periods. From this the following figures are taken.

TABLE XVII—TOTAL NUMBER OF DAYS ON WHICH SPECIFIED AMOUNTS OF RAIN FELL IN SPECIFIED TIMES DURING THE TEN YEARS 1925 TO 1934

	Average annual fall	0·2 in.				0·4 in.				1·0 in.			
		⩽ 6 min.	⩽ 15 min.	⩽ 30 min.	⩽ 60 min.	⩽ 15 min.	⩽ 30 min.	⩽ 60 min.	⩽ 2 hours	⩽ 1 hour	⩽ 2 hours	⩽ 5 hours	⩽ 24 hours
	in.	*days*											
Kew Observatory ..	23·8	16	28	44	85	6	13	18	34	4	4	5	15
Felixstowe	20·3	9	20	41	65	4	6	14	24	1	1	3	8
Mount Batten	33·1	6	16	43	117	3	7	15	41	0	1	8	44
Renfrew	37·0	9	17	38	110	5	7	10	40	0	1	4	37
Eskdalemuir	56·3	10	28	82	243	3	9	25	111	1	1	21	141
Armagh	31·7	6	26	42	84	3	11	15	26	1	1	4	14
Valentia	55·7	4	16	66	194	3	4	16	75	0	0	5	80

In reading this table it must be remembered that the figures in succeeding columns are inclusive of those in preceding ones.

In order to get figures representing an " average " station, Bilham excluded Eskdalemuir and Valentia at which rainfall is exceptionally high, and considering 16 other stations derived a formula from which he was able to compute the following table as representing the likelihood of rain of various amounts occurring in short periods over the British Isles.

TABLE XVIII—COMPUTED AMOUNTS OF RAIN FALLING IN STATED TIMES

Frequency	⩽5 min.	⩽10 min.	⩽15 min.	⩽20 min.	⩽30 min.	⩽45 min.	⩽60 min.	⩽90 min.	⩽120 min.
	inches								
One day in a year..	0·18	0·23	0·28	0·31	0·36	0·41	0·46	0·52	0·58
One day in 2 years	0·24	0·31	0·36	0·40	0·46	0·52	0·58	0·66	0·72
One day in 5 years	0·33	0·43	0·49	0·55	0·62	0·71	0·78	0·88	0·98
One day in 10 years	0·43	0·54	0·62	0·68	0·77	0·88	0·97	1·10	1·20
One day in 20 years	0·54	0·68	0·78	0·85	0·97	1·10	1·20	1·36	1·47
One day in 40 years	0·68	0·85	0·97	1·06	1·19	1·35	1·48	1·67	1·82
One day in 60 years	1·06	1·31	1·49	1·61	1·82	2·06	2·24	2·52	2·73

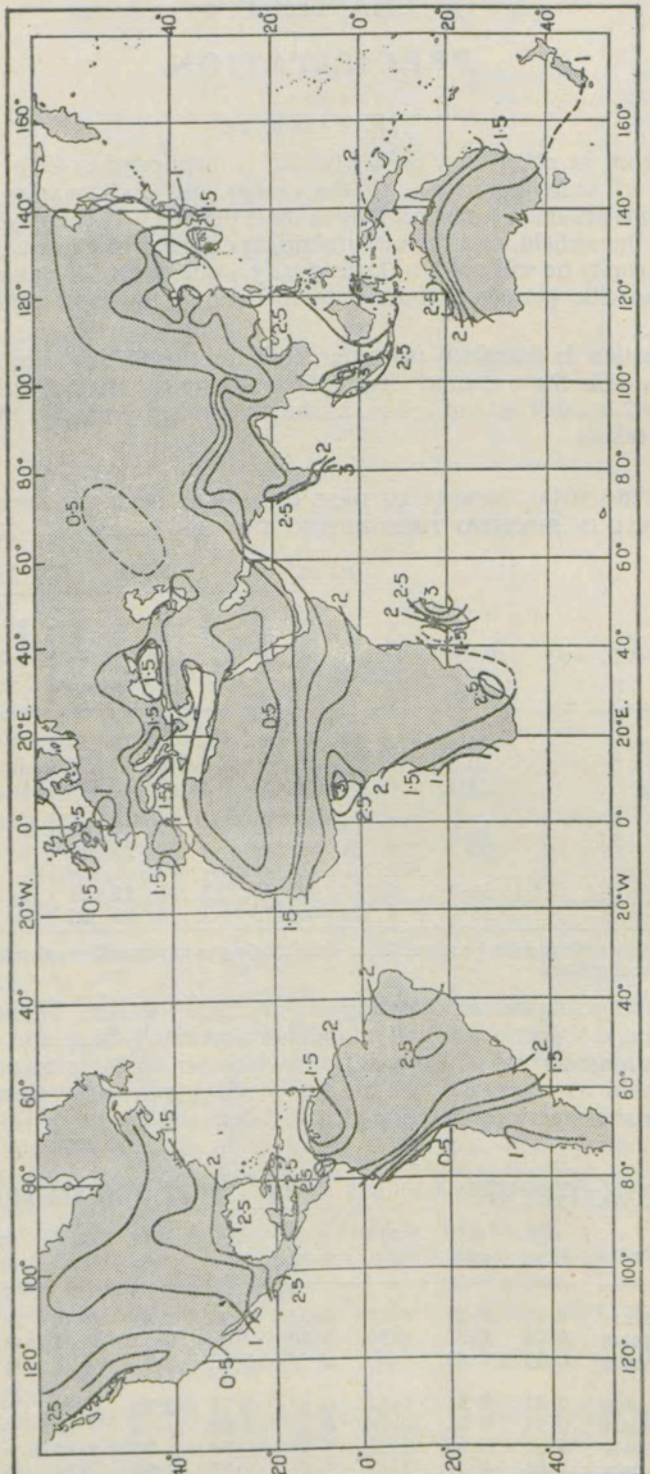

FIG. 9.—MAXIMUM RAINFALL (IN INCHES) IN 1 HOUR EXPECTED ONCE IN 2 YEARS

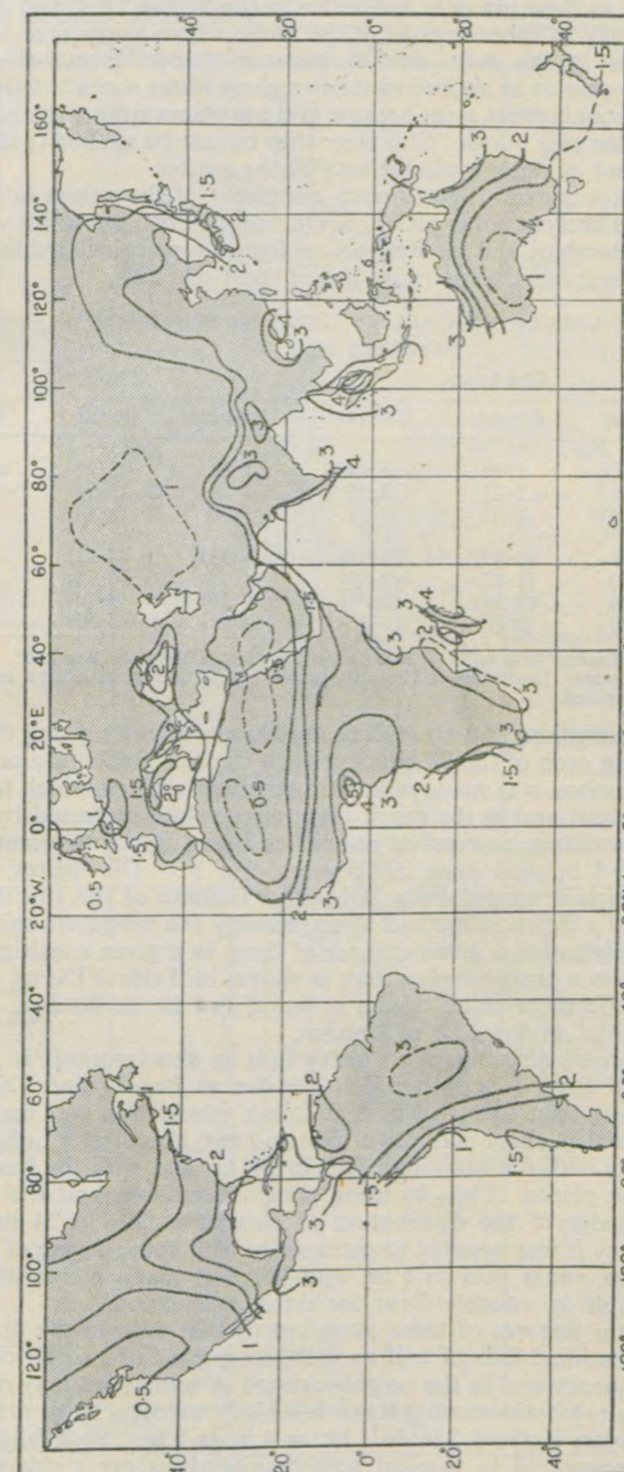

FIG. 10.—MAXIMUM RAINFALL (IN INCHES) IN 2 HOURS EXPECTED ONCE IN 2 YEARS

Such figures as these are only applicable to the British Isles, and with some degree of accuracy to other regions of the globe where heavy precipitation in short periods is in the main due to summer thunderstorms of moderate intensity. They cannot be applied to those regions where summer temperatures are high and vapour content great because in those places more water is available to produce sudden rain bursts. Still more they cannot be applied to the tropics where the amount of water available may be far greater.

To make a comparison figures were calculated of the values in one hour and two hours as likely as not to occur once in one year, two years, five years, etc., at Batavia and Bombay, and for comparison figures were calculated for Calshot on exactly the same basis. The result is given in Table XIX.

TABLE XIX—VALUES OF RAINFALL AS LIKELY AS NOT TO OCCUR ONCE IN SPECIFIED PERIODS

Period	One hour			Two hour		
	Batavia	Bombay	Calshot	Batavia	Bombay	Calshot
yr.			*inches*			
1	2·16	2·08	0·44	2·91	2·92	0·63
2	2·44	2·22	0·53	3·26	3·14	0·78
5	2·75	2·47	0·63	3·80	3·89	0·87
10	3·00	(2·65)	(0·71)	(4·33)	(4·22)	(1·03)
25	(3·43)	(2·87)	(0·82)	(4·77)	(4·75)	(1·20)
50	(3·69)	(3·04)	(0·90)	(5·16)	(5·14)	(1·32)
100	(3·96)	(3·20)	(0·98)	(5·56)	(5·53)	(1·44)

Periods used.—Bombay 1921 to 1937, Batavia 1866 to 1936, Calshot 1920 to 1940. Figures in brackets are extrapolated. In the case of Bombay excessive falls of 3·90 in. in 1 hr. and 6·44 in. in 2 hr. have been omitted.

It must be recognised that these data are based on tables giving the hourly amounts of fall in each of the 24 hours of each day (i.e. the hourly periods are fixed). A comparison was made with the maximum amount which fell in any 60 min. at Bombay, and in the result there were values increased by $\frac{1}{4}$ in. to $\frac{1}{2}$ in., e.g. the maximum amount of rainfall as likely as not to occur once in one year was 2·3 in. and once in 10 years, 3·1 in. The figures, given in Table XVIII, which is quoted from Bilham's "Climate of the British Isles,"[7] are calculated by a different method again, namely the maximum rainfall in a given period likely to fall a given number of times in a given number of years. This method gives a smaller value than is shown in Table XIX, as would be expected, the differences being of the order of 0.2 in. at Batavia, but only 0·06 in. or 0·07 in. in the case of Calshot.

The geographical distribution of heavy falls in short periods is shown in broad outline in Figs. 9 and 10 which are due to Brooks and Carruthers.[8] These charts have been constructed as follows : correlation was made of the amounts measured in short periods (of one and two hours) at a rather limited number of places with the maximum falls in 24 hr. and with the frequency of thunder at these places. Then by using these correlations and the far more extensive knowledge of the distribution of maximum falls in 24 hr. and of thunder frequency it was possible to extrapolate with some degree of precision the probable maximum falls in 1 hr. and 2 hr. at many places where data were not available in suitable form for direct calculation.

The significant features of these maps are (i) that even in the driest areas of the globe occasional falls of half an inch in an hour or two do occur with appreciable frequency and in the neighbourhood of mountains may cause very serious flooding ; (ii) the most intense fall likely to occur with a frequency of once in two years is about 3 in. in 1 hr. or 4 in. in 2 hr. Such falls are most likely to be encountered in tropical neighbourhoods where winds with long sea track have struck mountainous regions.

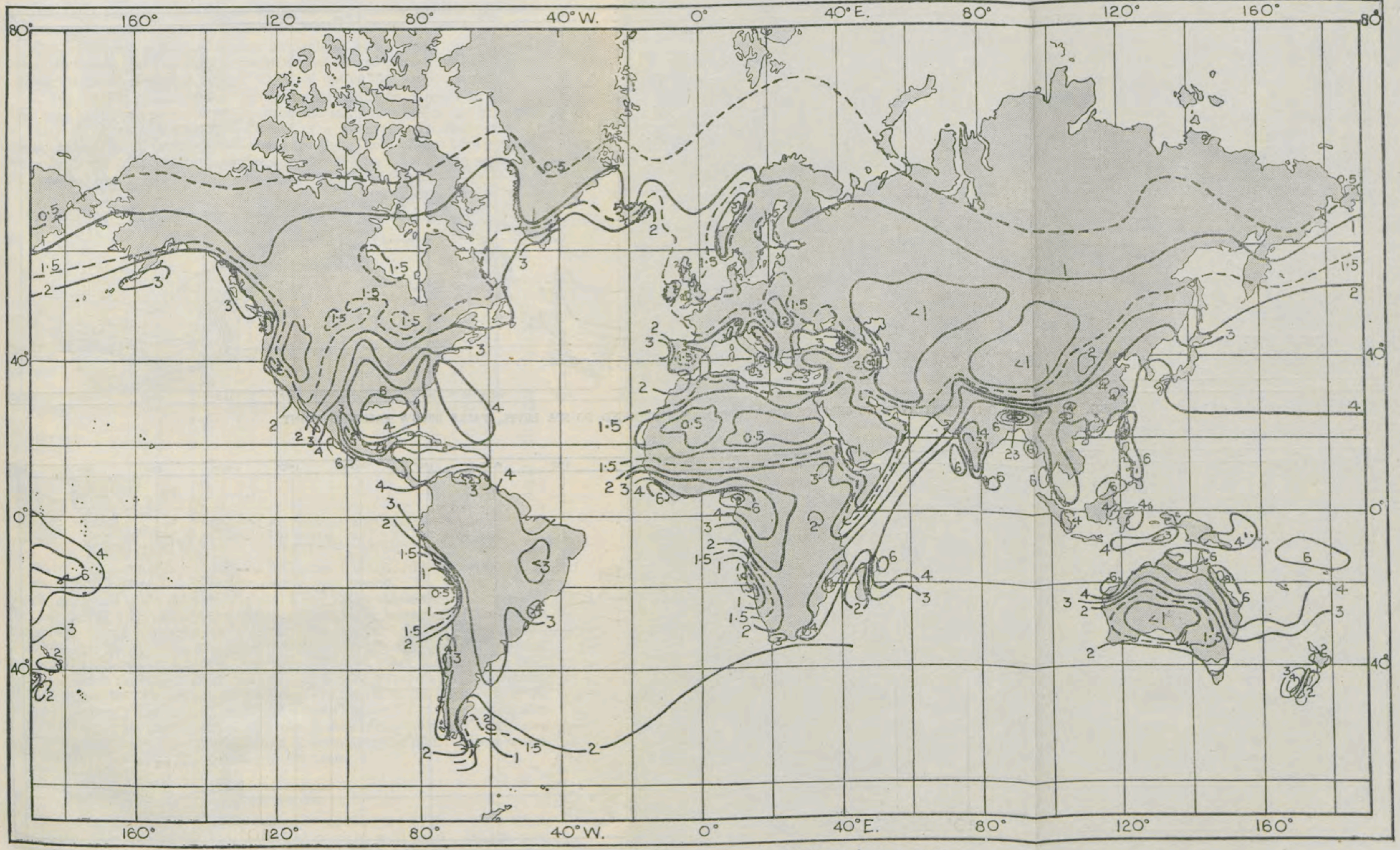

FIG. 11.—MEAN ANNUAL MAXIMUM RAINFALL (IN INCHES) IN A DAY

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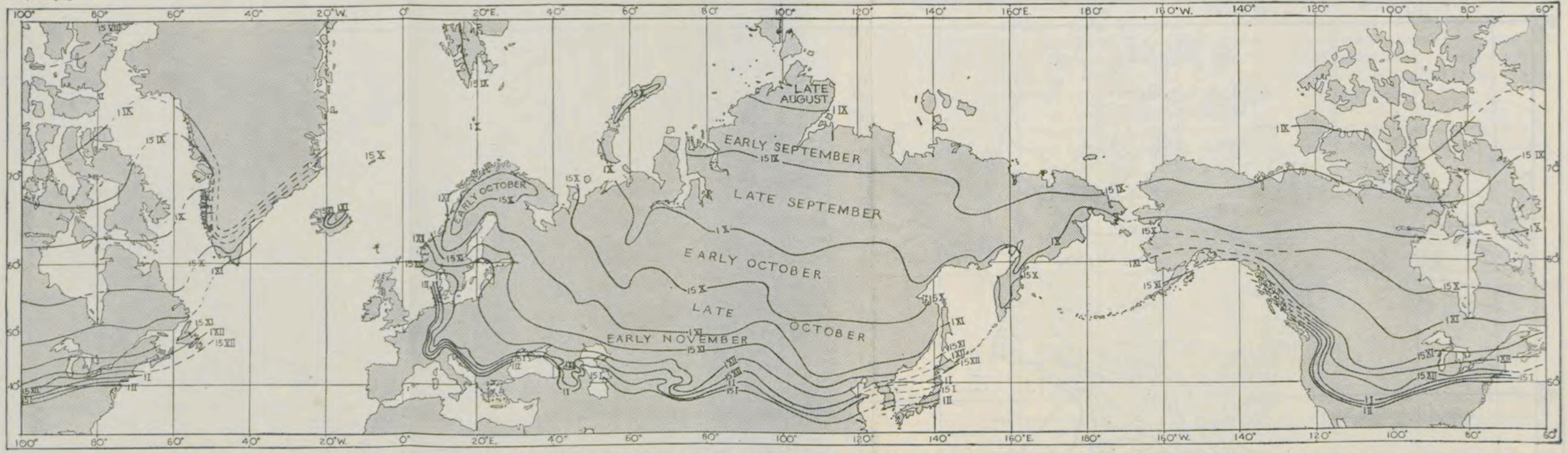

FIG. 13.—DATES ON WHICH AVERAGE SURFACE AIR TEMPERATURE, REDUCED TO SEA LEVEL, FALLS BELOW FREEZING POINT

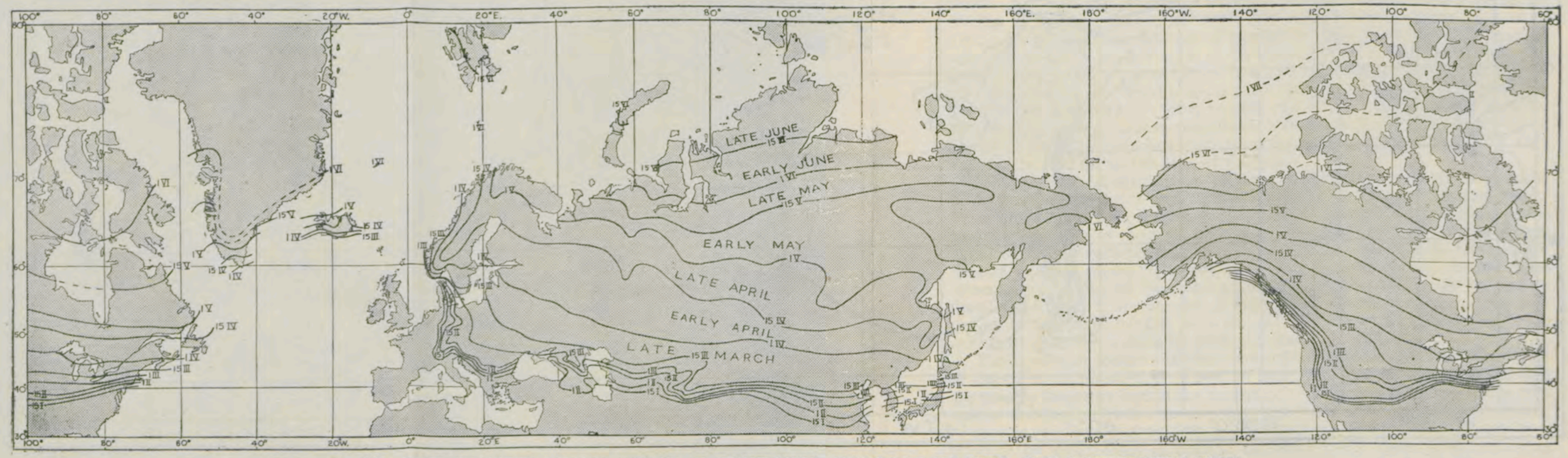

FIG. 14.—DATES ON WHICH AVERAGE SURFACE AIR TEMPERATURE, REDUCED TO SEA LEVEL, RISES ABOVE FREEZING POINT

In using these maps, it has to be remembered that they are greatly generalised and so give only a broad outline of the situation. This is necessarily so since observational data of these short-period falls are so scanty.

The occurrence of falls of various amounts in 24 hr. is reported for many places, but often these data are summarised not as frequencies but as extremes, i.e. the maximum fall in 24 hr. ever recorded during any particular month.

A map showing mean annual maximum fall in 24 hr. is given in Fig. 11. This map represents very nearly the probable maximum fall in 24 hr. which is likely to be exceeded in 50 years out of a hundred. To show how the magnitude of the fall increases as the odds lengthen Table XX has been prepared which gives for certain stations the probable maximum fall in 24 hr. which will be exceeded in 1 yr., 5 yr., 10 yr., 25 yr., 50 yr., and 100 yr.

TABLE XX—AMOUNTS OF RAINFALL IN 24 HR. WHICH ARE AS LIKELY AS NOT TO BE EXCEEDED IN A GIVEN NUMBER OF YEARS

	Rainfall—amounts in 24 hr.							Annual fall	
	1 yr.	5 yr.	10 yr.	25 yr.	50 yr.	100 yr.	Period	Average amount	Period
	in.	in.	in.	in.	in.	in.	yr.	in.	yr.
Kew	1·2	1·7	2·0	2·3	2·3	2·7	75	23·8	35
Newquay	1·4	2·0	2·3	2·5	2·7	2·9	34	33·2	35
Malta*	2·5	4·1	5·0	6·7	7·1	8·0	80	22·4	17
Helwan	0·4	0·9	0·9	1·1	1·6	1·8	35	1·4	27
Karachi	2·6	5·4	6·1	7·1	8·3	9·3	46	7·5	43
Batavia	4·1	5·9	7·2	8·3	9·3	10·2	45	69·6	72
Hongkong* ..	6·6	9·2	10·2	11·5	12·5	13·6	38	84·9	50
Lagos	5·2	7·0	7·9	8·7	9·3	10·0	45	71·7	30
Montevideo ..	3·4	5·2	6·3	6·8	7·8	8·6	24	37·4	56
Trinidad* ..	2·4	3·1	3·3	3·6	3·9	4·2	41	63·3	55
New York ..	3·3	4·6	5·1	5·8	6·3	6·8	40	42·9	50
Denver	1·6	2·3	2·6	2·9	3·1	3·3	44	14·1	50
San Francisco ..	2·2	3·1	3·2	3·5	3·6	3·9	46	22·0	50

* Malta .. .. A value of 11·6 in. recorded in 1913 has been omitted.
Hongkong .. A value of 21·0 in. recorded in 1926 has been omitted.
Trinidad .. A value of 5·9 in. recorded in 1892 has been omitted.

Table XX was constructed in the following manner: the maximum fall in 24 hr. was tabulated for each year over a long period. The means of these values are given in the column headed " 1 yr.". The values were then grouped in consecutive 5-yr. periods and the maximum value in each 5 yr. was again tabulated, the means are given in the column headed " 5 yr.". This process was repeated by grouping in consecutive 10 yr., 25 yr., etc. When the period covered by the record was less than the number of years shown at the head of the column the values given in the column were extrapolated by assuming a logarithmic law, i.e. maximum rainfall proportional to the logarithm of the number of years. The values given in the column headed " 1 yr." are comparable with Fig. 11. In three cases where the highest maximum was considered abnormal the values have been omitted in compiling the table. These values are, however, stated in the footnote to the table.

§ 22. SNOW

The main items on which information is required are (i) the regions which are likely to be snow covered for a week or more in most years; (ii) the dates between which snow is liable to affect airfield surfaces; and (iii) the maximum depth of snowfall which is likely to occur and which may have to be disposed of.

(*a*) *Regions where snow may be expected to lie.*—The regions of the northern hemisphere where snow may be expected to lie for longer than a few days are shown in Fig. 12 which gives the average duration in days per annum. For this purpose a day of snow lying is a day on which more than half the ground representative of the station is covered with snow. The definition of the ground representative of the station is the flat land easily visible from the station and not differing from it in altitude by more than 100 ft.

The variation of snow cover with altitude is important. In the eastern Alps for example, the average number of days per annum with snow cover at the morning observation (called Andauer by the Austrian meteorologists) can be expressed by the formula $L = a + 0{\cdot}1\,h$ where L is the average number of days per annum with snow cover, a is a constant which has the value 23 in the eastern Alps and h is the height in metres, i.e. L increases by 10 days for each 330 ft. In Scotland on the other hand Gordon Manley[9] gives an increase of about 10 days for every 200 ft. of height.

To give an indication of the variation in the duration of snow cover with height elsewhere Table XXI is given here to show the duration at different heights in the Vosges and at Berchtesgaden.

TABLE XXI—AVERAGE ANNUAL DURATION OF SNOW COVER IN DAYS AT VARIOUS HEIGHTS

Height								
metres	300	400	500	600	700	800	900	1,000
feet	984	1,312	1,640	1,968	2,297	2,625	2,953	3,281
Vosges	21	32	52	70	86	100	114	128
Berchtesgaden ..	—	—	84	110	124	132	140	146

In regard to the southern hemisphere snow is only likely to be an important consideration in the Antarctic, the southern part of South America, the islands of the Southern Ocean and the higher elevations of the Andes.

(*b*) *Dates between which snow cover is liable to be of importance.*—Figs. 13 and 14 show the average dates of the onset of the 32° F. isotherm and of the passing of the 32° F. isotherm for the northern hemisphere. Snow cover usually occurs from one to three weeks before the former of these dates and lasts until about one to four weeks after the latter, but as a rule it is comparatively transient outside these limiting dates so that the maps show the average dates between which snow is usually found covering the landscape. The dates are for the average year ; in individual years the dates of both beginning and ending of the transient periods of snow cover may vary greatly.

An analysis of 20 winters (January, February and March 1925 to 1944) was made for north-west Germany, and this showed that the final thaw, i.e. the end of a long spell of day frost, was distributed as follows :—

TABLE XXII—TIMES OF OCCURRENCE OF FINAL THAW IN NORTH-WEST GERMANY

Mid Jan.	Late Jan.	Early Feb.	Mid Feb.	Late Feb.	Early Mar.	Late Mar.
1	1	2	1	5	4	4

In the remaining 2 years, 1925 and 1930, the winters were generally mild, frost never penetrated appreciably into the ground, no settled snow cover occurred and there were no real thaws. In 14 of the other 18 years the thaw was quick and in 4 years it was slow.

Further east in Europe the snow cover occurs with greater regularity, for instance near Moscow the snow cover begins some time between October 20 and November 30 and ends some time between April 8 and 19.

The snow cover acts as a blanket to the soil beneath, and in consequence a few feet below the surface the soil is unlikely to be frozen even in so cold a region as Moscow. A special examination was made in one year at Sodankyla, and there it was found that with a foot or two of snow the ground did not freeze at 3 ft. below the surface though the temperature of the surface of the snow was at times as low as −10° F. or even −30° F. (say −25° C. to −35° C. in round figures).

As soon as the snow thaws the ground becomes very waterlogged since the water from the thawed snow cannot drain through the frozen soil. It may take 10 days for the ground to become thoroughly thawed and drained ; the drainage may lead to flooding of low-lying ground.

(*c*) *The maximum depth of snow likely to occur.*—The snow settles after it has fallen and becomes compressed, so that at places where in most years the snow cover lasts for several months there is a gradual increase in depth as the season progresses and also an increase in the density of the snow. The settling of the snow is more rapid if the air temperature at the time of fall is near freezing than if it is much below. When once thawing starts the snow depth decreases rapidly. At Moscow for instance, the 17 in. of snow usually takes 12 days to melt at the end of March.

Table XXIII gives an idea of the comparative densities of snow.

TABLE XXIII—DENSITY OF VARIOUS TYPES OF SNOW

Wild snow	0·02	New firn snow*	0·5
New loose snow	0·1	Old firn snow	0·6
Settled snow	0·2 to 0·3	Very wet snow	0·8
Average wind-toughened snow	0·3	Glacier ice	0·9
Wind crust and slab	0·3 to 0·5	Water	1·0

* Firn snow is the name given to the cover formed when the snow flakes congeal and become a mass of opaque grain.

The build-up of the snow cover is shown for certain places in Table XXIV which gives the average depth of snow and the absolute maximum in depth for certain places.

TABLE XXIV—AVERAGE DEPTH AND ABSOLUTE MAXIMUM DEPTH OF SNOW COVER

	Lat.	Long.	Height	No. of years of observation	Depth of snow	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
	N.	E.	ft.			inches							
Bjørnsund	69° 28′	30° 11′	21	25	Average	2	7	13	18	23	26	24	10
					Maximum	*18*	*26*	*30*	*36*	*45*	*45*	*39*	*37*
Leningrad	59° 56′	30° 16′	28	20	Average	0	1	4	7	12	11	2	0
					Maximum	–	–	–	–	–	–	–	–
Moscow	55° 47′	37° 40′	548	10	Average	0	2	4	10	16	17	6	0
					Maximum	–	–	–	–	–	–	–	–
Bergen ..	60° 24′	5° 19′	144	7	Average	0	0	0·6	0·6	0·4	0·6	0	0
					Maximum	*0*	*2*	*12*	*10*	*15*	*10*	*0·8*	*0*
Stockholm	59° 21′	18° 4′	146	25	Average	0	0·4	2	4	5	4	0·4	0
					Maximum	*3*	*9*	*28*	*29*	*24*	*30*	*18*	*2*
Ramner (near Oslo)	59° 22′	10° 15′	30	25	Average	0	1	5	10	13	13	4	0
					Maximum	*10*	*19*	*31*	*49*	*47*	*49*	*35*	*7*
Niigata ..	37° 56′	139° 3′	24	—	Average	0	0	5	14	12	6	4	0
					Maximum	–	–	–	–	–	–	–	–
Sofia ..	42° 42′	23° 20′	1,804	10	Average	0	3	6	6	6	4	0	0
					Maximum	*0*	*13*	*14*	*14*	*13*	*18*	*0·4*	*0*
Tchiflik	43° 48′	26° 2′	509	10	Average	0	8	8	9	8	8	0·4	0
					Maximum	*0*	*39*	*20*	*17*	*19*	*4*	*4*	*0*

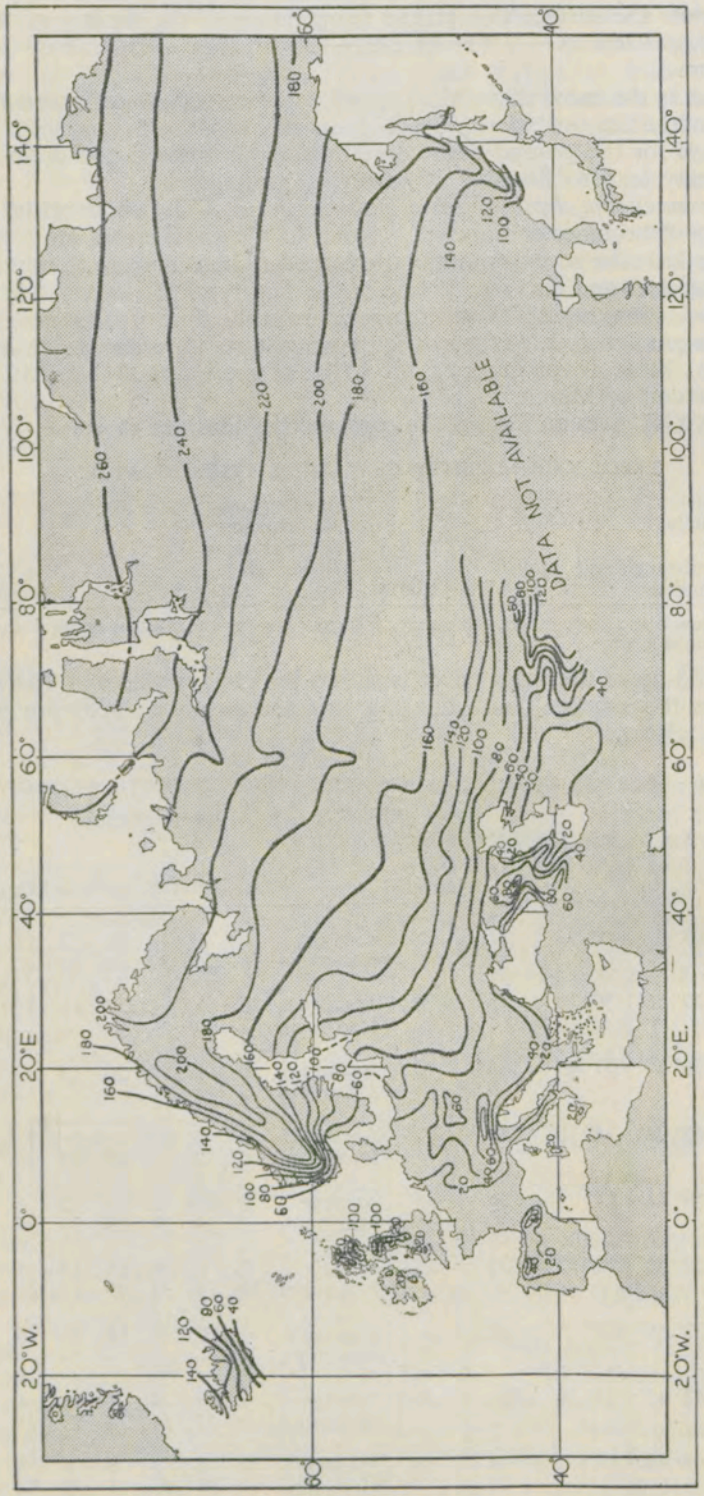

FIG. 12.—AVERAGE DURATION OF SNOW COVER

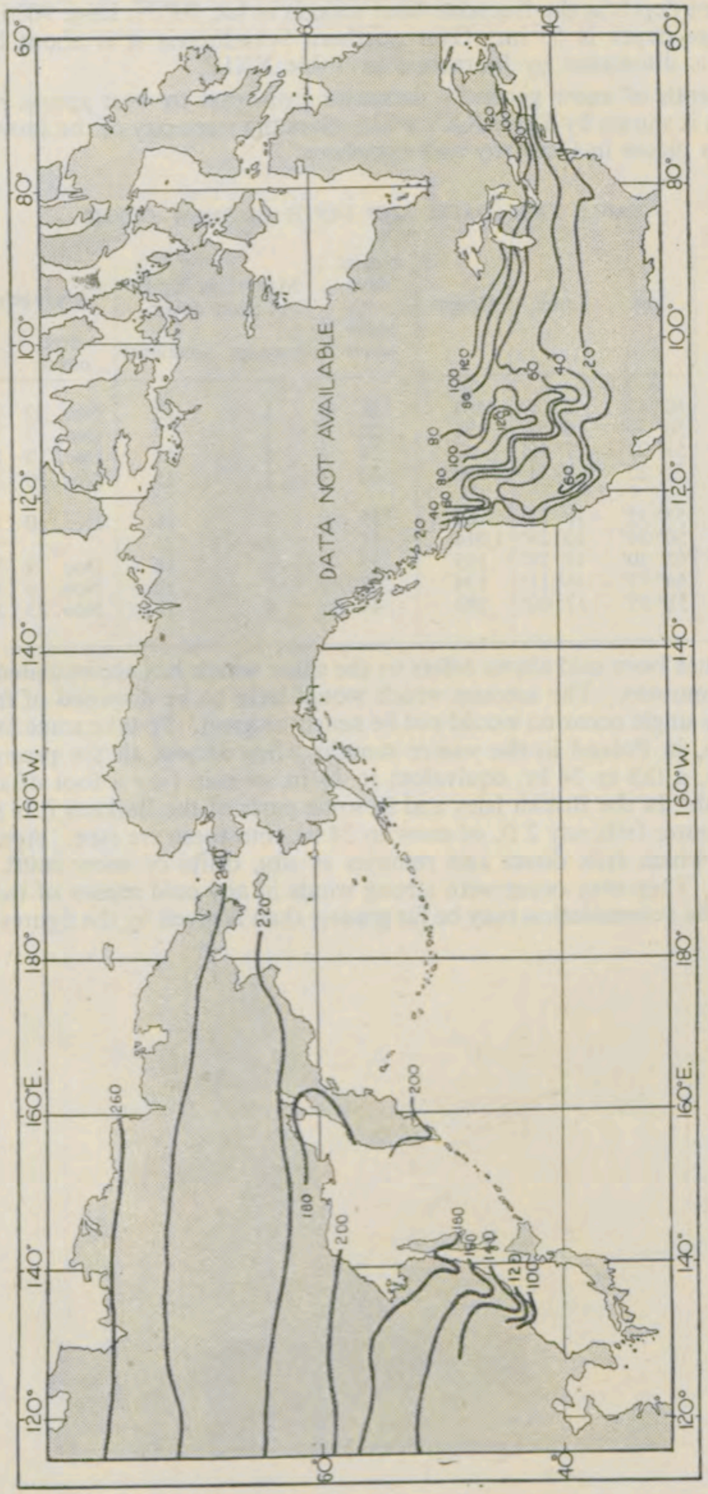

FIG. 12—AVERAGE DURATION OF SNOW COVER—*continued.*

On the whole March is the month of greatest snow depth. In that month the greatest depth in the Eurasian land mass is in lat. 70° N. long. 90° E. where the average depth is 55 in. Over northern Scandinavia it is about half this depth as is illustrated by Bjørnsund in Table XXIV.

The depth of snow generally decreases from east to west across northern Europe as is shown by Table XXV which gives the summary of the snow depths for certain places in Germany and elsewhere.

TABLE XXV—DATES AND DEPTH OF SNOW COVER

	Lat.	Long.	Height	No. of days with snow cover	Maximum depth of snow cover: Average	Maximum depth of snow cover: Absolute	Average date of first cover	Average date of last cover
	N.	E.	ft.		in.	in.		
Aachen ..	50° 47′	6° 06′	663	21	5	12	Dec. 22	Mar. 5
Cologne ..	50° 56′	6° 57′	171	23	3	7	Dec. 17	Mar. 9
Emden ..	53° 22′	7° 12′	10	24	4	11	Dec. 19	Mar. 16
Canel ..	51° 20′	9° 31′	650	40	7	15	Nov. 30	Mar. 14
Luneberg..	53° 15′	10° 24′	66	35	7	16	Dec. 10	Mar. 22
Meiningen	50° 34′	10° 25′	1,014	55	9	21	—	—
Berlin ..	52° 30′	13° 25′	115	37	6	16	Dec. 9	Mar. 16
Koslin ..	54° 12′	16° 11′	134	57	11	19	Nov. 19	Mar. 19
Breslau ..	51° 07′	17° 02′	387	44	8	17	Nov. 25	Mar. 20

What has been said above refers to the snow which has accumulated over a period of months. The amount which would have to be disposed of from the fall on any single occasion would not be nearly as great. To take some examples at random, in Poland in the winter months when almost all the precipitation is as snow, a fall in 24 hr. equivalent to 1¼ in. of rain (say a foot of snow) is exceptional. In the British Isles and in some parts of the Balkans it is possible to have greater falls, say 2 ft. of snow in 24 hr., but these are rare. Apart from the snow which falls direct and remains *in situ*, drifts of snow must not be forgotten. They may occur with strong winds in any cold region of the globe, and then the accumulation may be far greater than is given by the figures quoted above.

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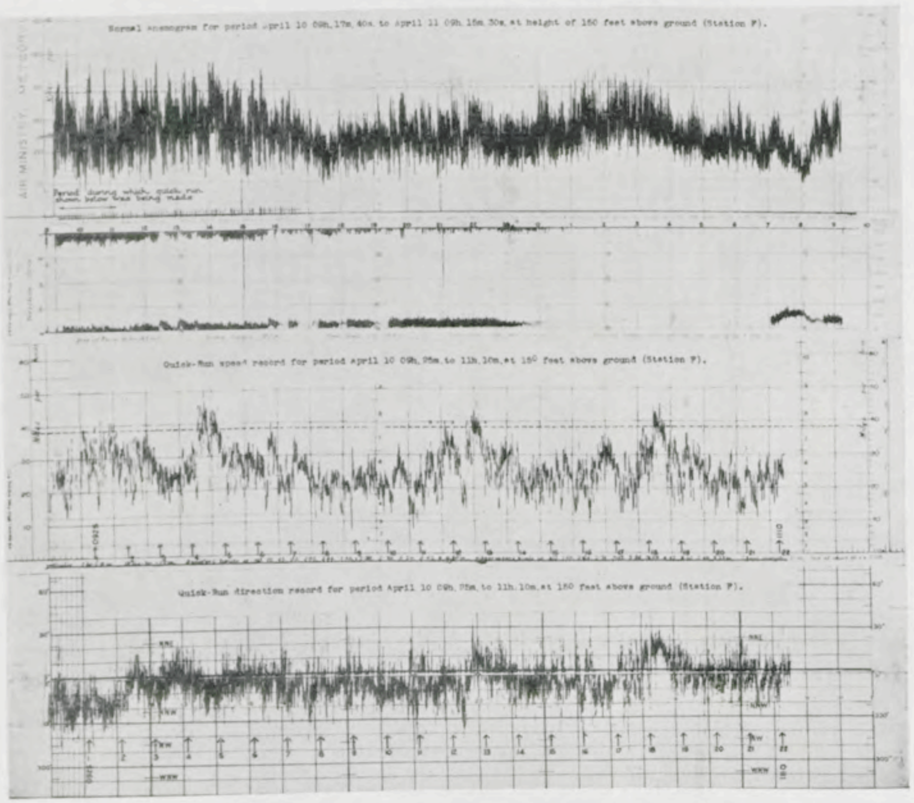

FIG. 15.—ANEMOGRAMS MADE AT CARDINGTON APRIL 10–11, 1929

showing normal and quick-run records, the former being made during 24 hr., the latter during 2 hr. The quick-run records reveal the finer structure of wind gusts and lulls.

CHAPTER V

WIND

The effects of wind on the design and lay-out of airfields may be divided under two headings :—

(i) the maximum wind likely to occur at any place ; this is needed in order that the designer may make allowance in the strength of buildings, towers, etc. ; and

(ii) the frequency with which winds will inhibit the use of any particular design of runway.

§ 23. MAXIMUM WINDS

(*a*) *Anemometers.*—At many places there are anemometers which record the speed of the wind continuously. In many cases the direction is also recorded at the same time. The degree of precision of the anemometer depends on its design and varies widely. In some it is only possible to obtain the run of the air during a period of time, as for instance in cup anemometers. In some designs it is possible to obtain the run during five minutes or even less, but during any such period there are many fluctuations in the wind which cannot be differentiated.

In the " swinging-plate " types of anemometer the short-period fluctuations of the wind are recorded by the position of the plate. A swinging-plate type can be so designed as to indicate the maximum gust which occurs, but inertia limits the efficiency to some extent.

In the Dines anemometer, in the anemobiagraph and in the French anémo-cinémograph the record shows the fluctuations of the wind in time by a continuous record, see Fig. 15, from which the extreme excursions of the pen during gusts can be measured. However, even in the Dines anemometer the inertia of the moving parts (a float and its attached pen) and the effect of damping due to the air pressure being transmitted along a pipe causes the instrument not to be truly dead beat. A careful examination of a set of anemometers at Cardington resulted in the conclusion that mean values of wind derived from the anemograms of the Dines instruments were untrustworthy if taken over a period less than 5 sec. This, however, does not mean that the Dines anemograph smooths the wind values over 5-sec. intervals, so it may be reckoned that the extreme gusts recorded by a Dines instrument give approximations to the wind speed lasting for 1 or 2 sec. A more serious cause of error in the measurement of gusts is a tendency of the pen to fail to record when first it moves over a fresh part of the paper. This causes the trace of isolated gusts to be lost. How far this error has affected past records is not known.

These limitations affect all tables and estimates of the maximum gusts which occur in the different localities of the globe.

(*b*) *Form of gusts.*—In general it is found that gusts and squalls have a characteristic form consisting of a sharp rise followed by a gradual fall. As an example Fig. 16 is shown, the anemogram of a squall that struck Maiduguri, Northern Nigeria. In that case the wind increased from 10 to 55 kt. in 5 min. but took an hour and a quarter to decrease again. A similar structure is found in the shorter-period gusts embedded in the general stream. In the lower part of Fig. 15 there is the reproduction of a " quick-run " record in which the time scale is stretched by 12 times. The sharp rises and gradual falls can be recognised just after the " time marks " 4, 6 and 7 and again in the gust between time marks 12 and 13. Even when the time scale is stretched by 144 times the

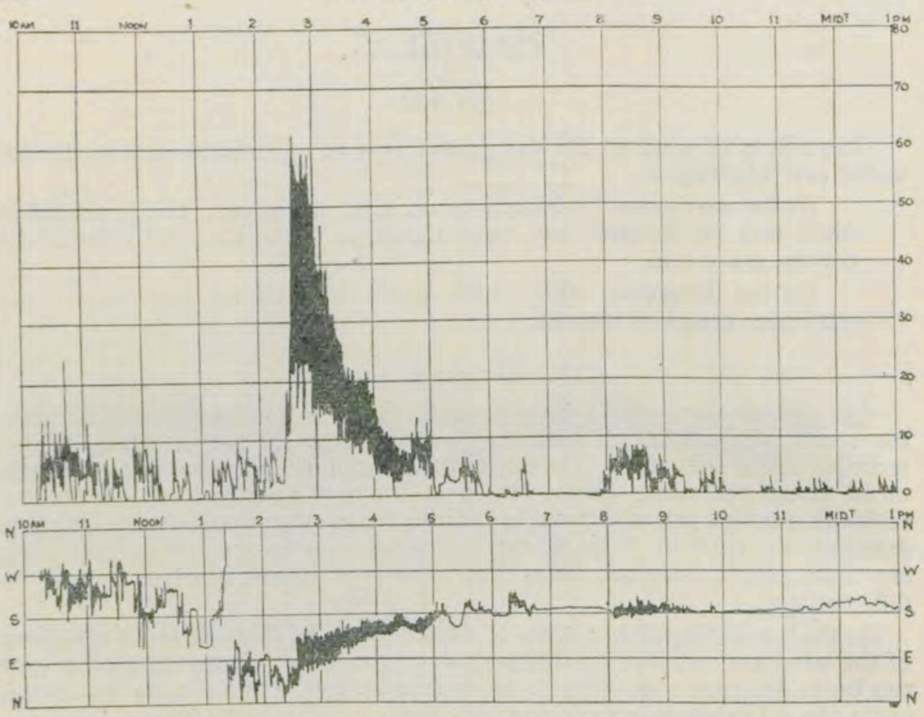

FIG. 16.—ANEMOGRAM OF A SEVERE LINE-SQUALL AT MAIDUGURI, NORTHERN NIGERIA, OCTOBER 2, 1942

From 1000 until 1430 the wind slowly backed from W. to NE. remaining below 10 m.p.h. most of the time. The squall struck at 1435 the wind veering suddenly to ESE. with a gust of over 60 m.p.h. The wind then rapidly veered and decreased remaining rather west of south and falling very light from 1700 onwards

same is seen, for example, in a case illustrated in a detailed examination of the structure of wind which records the results of the Cardington experiments.[10] In that particular instance though the wind was not very strong the speed increased rapidly from 16 kt. (18 m.p.h.) to 29 kt. (33 m.p.h.) in a matter of 5 sec., fluctuated about 26 kt. (30 m.p.h.) for about 30 sec. and then took a further 30 sec. to fall back to 17 kt. (20 m.p.h.). This was found to be characteristic on many occasions, and so it is in general to be expected that accelerations in the wind are more rapid than retardations. To show the magnitude of the accelerations in gusts certain wind records made at Cardington on a very open time scale were tabulated and the resultant frequency plotted. This is shown in Fig. 42 (top panel) of *Geophysical Memoirs* No. 54[10] in comparison with a normal curve of error. The values are derived from wind speeds averaged over 5 sec. and are in the unit miles per hour per 5 seconds. The mean wind speeds of the records used were 24 kt. (28 m.p.h.), 35 kt. (41 m.p.h.), 24 kt. (28 m.p.h.), 30 kt. (34 m.p.h.) and 24 kt. (28 m.p.h.) respectively. They show accelerations up to 14 kt./5 sec. (16 m.p.h./5 sec.). These measurements were made at Cardington over level country.

(*c*) *Variations of gusts from place to place*.—At Cardington anemometers were arranged to record simultaneously at points 350 ft. and 700 ft. apart, and the following conclusion was reached in regard to the horizontal dimensions of wind gusts.[10] " The comparison of simultaneous records from different anemometers does not reveal an identical wind pattern travelling over the anemometers even in those cases where the wind was blowing almost directly from one anemometer to another. In particular, it is exceedingly difficult, if not impossible in most cases, to follow pronounced gusts on successive

anemometers. The general conclusion is reached that an individual wind gust is an ephemeral phenomenon even over a stretch of 350 ft., though a group of gusts moves with approximately the mean wind speed." However, in a squall of the line-squall type, it is known that the wind gust may strike simultaneously along a front of a mile or more.

The observations at Cardington were made mainly at a height of 50 ft. above ground though some observations were made at 150 ft. The comparison of the maximum gusts showed that the general level of the strongest gusts during the same hourly periods of observation was greater at 150 ft. than at 50 ft. by about 10 or 20 per cent.

(*d*) *The maximum wind speeds at various places*.—In a paper " Wind in Britain " Gold[11] has discussed the frequency of occurrence and maximum speeds of the winds over the British Isles between 1909 and 1934. The highest gust ever recorded in the British Isles is 98 kt. (113 m.p.h.) at St. Anne's Head on January 18, 1945. Other well authenticated high gusts are 96 kt. (111 m.p.h.) reported at Scilly and 94 kt. (108 m.p.h.) at Tiree. At Croydon 70 kt. (81 m.p.h.) is the highest gust recorded and this is fairly representative of inland places in England. The maximum hourly wind speeds for the same places are St. Anne's Head 70 kt. (80 m.p.h.), Scilly 66 kt. (76 m.p.h.), Tiree 58 kt. (67 m.p.h.) and Croydon 44 kt. (51 m.p.h.).

The ratio found by Gold between the extreme gust and the maximum hourly wind lies between 1·3 and 2·1 when the South Kensington record is omitted which gives 2·6 and is in a very disturbed situation.

The frequency of various ratios is shown in Table XXVI.

TABLE XXVI—FREQUENCY OF VARIOUS VALUES OF RATIO OF MAXIMUM GUST TO MAXIMUM HOURLY WIND FOR 42 STATIONS IN THE BRITISH ISLES

Ratio	1·3	1·4	1·5	1·6	1·7	1·8	1·9	2·0	2·1	2·6
Number	1	9	10	6	5	3	4	1	2	1

When grouped according to exposure the ratio for coastal stations falls mainly in the groups 1·4 and 1·5 ; for inland country stations principally in the groups 1·6 to 1·8 ; and for inland towns in the groups 1·9 to 2·1.

An examination of the Cardington data in which the maximum gust in any hour was compared with the mean wind speed during the same hour showed that with winds of 26 kt. (30 m.p.h.) or more at the level of 50 ft. the ratio was usually 1·5 or 1·6 but at 150 ft. the ratio was usually 1·4 or 1·5. Another comparison made at Cardington was between the maximum gust at 150 ft. above ground and the pressure gradient at the time, the latter being converted into " geostrophic wind speed ". The frequency of ratio between the maximum gust and the geostrophic wind is shown in Table XXVII. The lower limit of a geostrophic wind speed of 26 kt. (30 m.p.h.) was chosen more or less arbitrarily. The complete table may be seen in *Geophysical Memoirs* No. 54.[10]

TABLE XXVII—FREQUENCY OF OCCASIONS ON WHICH THE RATIO BETWEEN THE MAXIMUM GUST AT 150 FT. AND THE GEOSTROPHIC WIND FELL WITHIN CERTAIN VALUES

Geostrophic wind speed (kt.)	(m.p.h.)	Ratio : maximum gust to geostrophic wind													
		0·5	0·6	0·7	0·8	0·9	1·0	1·1	1·2	1·3	1·4	1·5	1·6	1·7	1·8
26–34	30–39	14	14	28	26	22	26	18	17	9	5	2	2	0	1
35–43	40–49	9	14	12	14	20	13	5	5	2	3	0	0	0	0
44–51	50–59	8	12	10	10	8	6	3	0	0	1	0	0	0	0
52–60	60–69	4	2	11	8	4	2	1	0	0	0	0	0	0	0
⩾60	⩾70	6	10	12	6	3	0	0	0	0	0	0	0	0	0
Total ..		41	52	73	64	57	47	27	22	11	9	2	2	0	1
Percentage ..		10	13	18	16	14	11	7	5	3	2	0·5	0·5	0	0

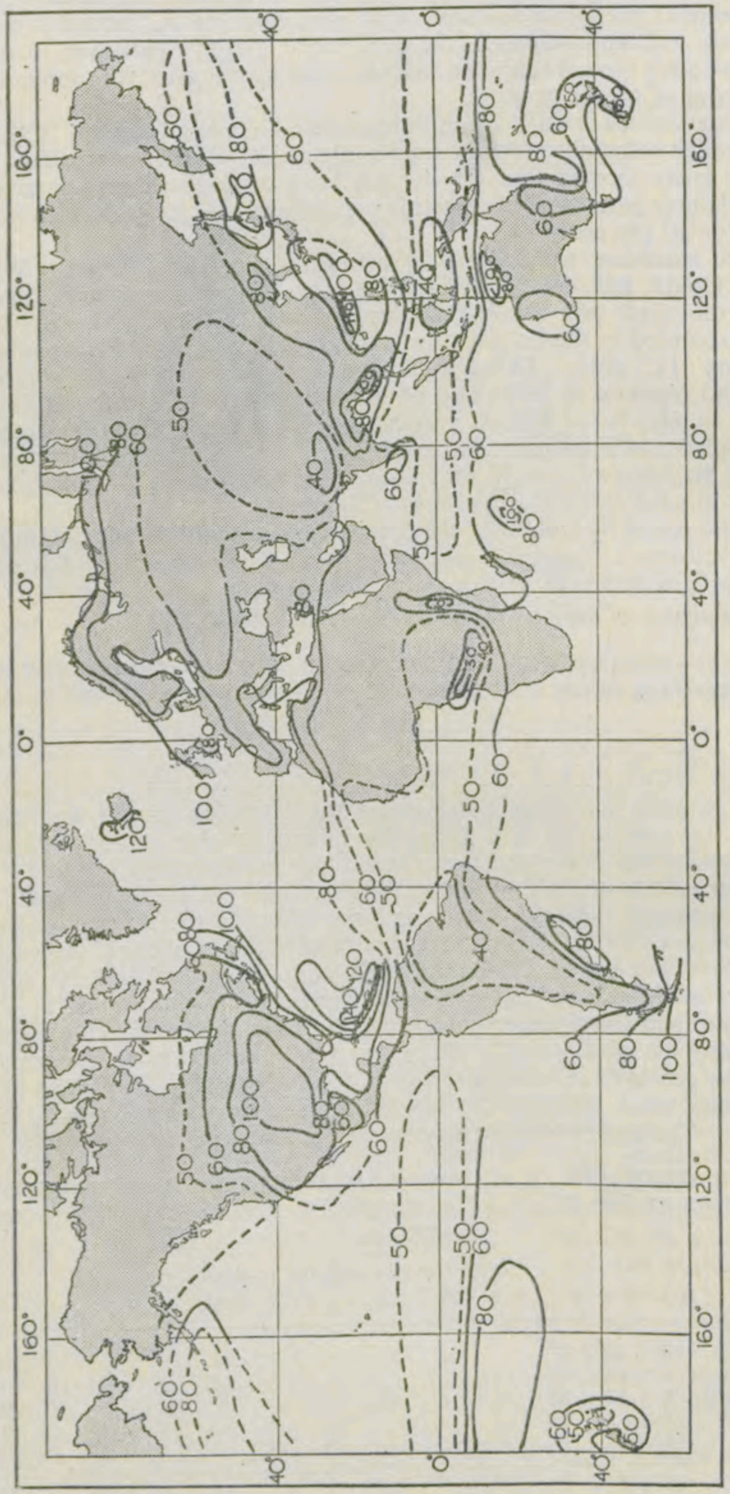

FIG. 17.—MAXIMUM GUST VELOCITY (IN KNOTS) LIKELY TO BE EXPERIENCED ONCE IN TEN YEARS

This is interesting in that it shows that with geostrophic winds above 55 kt. the maximum gust is not likely to exceed the geostrophic wind. The most usual value of the maximum gust is about $\frac{3}{4}$ or $\frac{4}{5}$ of the geostrophic wind.

The advantage of these figures is that these fractions are likely to obtain in other extratropical regions for stations surrounded by level country, and so if we know the magnitudes of the gradients likely to occur we can expect that the gusts at 150 ft. will not exceed the greatest geostrophic wind and will more usually be $\frac{3}{4}$ of the values of the geostrophic wind. A further check can be obtained by using what has been said above if we know the magnitude of the wind during an hour in very strong wind situations, for we can then expect the gusts to be half as much again as the mean wind on exposed coasts and $\frac{3}{4}$ as much again as the mean wind at inland sites.

(*e*) *Distribution of strong winds over the globe.*—To show where strong winds are to be expected the diagram shown in Fig. 17 has been prepared ; this gives the probable maximum wind speed which will occur at any place on an average once in 10 years. Places which are liable to be visited by American tornadoes were excluded from the calculations done for this diagram. These phenomena give rise to very strong winds, but in the case of the tornadoes they cover a very small area and even in the centre of the tornado belt the likelihood of a particular building being hit destructively by one is only once in many years.

The wind velocities in tropical revolving storms and tornadoes are very high. The maximum speed recorded, measured over a short period in a revolving storm, is 145 kt. (167 m.p.h.) which occurred at Hongkong on September 2, 1937.[13] But often records of very strong winds in tropical revolving storms have been lost because the anemometer has been blown away. An estimate of up to 175 kt. (200 m.p.h.) has been made at Great Abaco Island, on August 30, 1932. In a tornado a speed exceeding 175 kt. (200 m.p.h.) is said to have been attained.[14]

§ 24. LOCAL WINDS.

What has been said above refers to level country. In mountainous and broken country no such general rules can be given, but it is possible to see either on the ground or from a good map (on a moderate or large scale and showing contours) whether a region is liable to locally induced strong winds.

These local winds may be discussed under four main categories :

(*a*) Valley winds.
(*b*) Ravine winds.
(*c*) Headland winds.
(*d*) Sea breezes.

(*a*) *Valley winds.*—Usually the sides of a valley protect the floor from strong winds, but in valleys which penetrate into massive mountains diurnal winds occur, the day wind (anabatic wind) usually blowing up the valley, the night wind usually blowing down the valley. The valley wind is best developed in the deep, trough-like glaciated valleys whose cross-profile is U-shaped. In V-shaped valleys the wind is much less vigorous. The valley winds usually increase in strength from the surface up to 1,500 or 2,000 ft., at which level in very marked cases speeds of 30 to 40 kt. (35 or 45 m.p.h.) are sometimes recorded (for example in the Rhône Valley in the Alps).

(*b*) *Ravine winds.*—These occur in and near ravines which penetrate through mountain barriers. They occur when there is a large pressure difference level for level on the two sides of the mountain barrier and air travels down the ravine under this pressure gradient. The winds may be very strong in the ravine and may flow out over the surrounding country. Examples of this wind are the ravine wind at Genoa due to the differences of pressure between the Po Valley and the Gulf of Genoa, the kosava of the Danube south-east of Belgrade which sometimes exceeds 35 kt. (40 m.p.h.), and the vardar winds near Salonika. Many other instances might be given. The essential value of the information above is that strong local winds are likely to occur opposite the mouths of such deep ravines and can usually be deduced from a good topographical map, it being noticed that the ravine must not only penetrate into but through the mountain barrier.

(*c*) *Headland winds.*—When a headland or the bluff of a mountain juts out into a plain, winds blowing along the mountain flank are materially increased in speed opposite the bluff.

(*d*) *Sea breezes.*—Sea breezes are not sufficiently strong in most places materially to affect the design of an airfield, but locally they may be one of the main features of the climate and attain very considerable speeds. The localities where strong sea breezes occur appear to be those where high mountains rise inland from a comparatively narrow coastal plain. As an example may be quoted Valparaiso, where, after setting in between 0900 and 1100, the sea breeze increases until 1400 or 1500 ; in the height of the summer it is reported to be so strong in the afternoons that people seek shelter and communication between shipping and the shore is difficult.

In the case of Berbera, which has been examined in some detail[15] the diurnal variation in the summer months is very pronounced ; from being calm at night the wind rises day after day to a speed of 25 or 35 kt., and veers from SW. in the morning to W. and NW. as the sea breeze becomes more and more effective.

§ 25. EFFECTS OF TOPOGRAPHY IN PRODUCING VERTICAL CURRENTS

If there is a hill or a ridge of hills to windward of an airfield there is a liability that vertical currents may be induced, either over the airfield itself or in its locality, which will affect aircraft taking off into the wind before they have gained sufficient height to clear the hills themselves.

If on the other hand the airfield is on a plateau there is a risk that aircraft coming in to land (into the wind) may encounter a downdraught over the escarpment of the plateau. In the case of an airfield sited in broken country there is a risk that winds may be abnormally turbulent and lead to heavy landings.

The flow of air over hills is discussed by Morgans[4] who gave a review of the state of knowledge in 1931. From this and other information, the following conclusions relative to vertical currents can be drawn.

Provided V_0, the wind above the hill, is less than 20 kt. (23 m.p.h.) the air flow is usually comparatively steady to leeward of the hill.

If V_0 is greater than 20 kt. (23 m.p.h.) the probability is that the motion over the slopes of the hill will be violently turbulent with large scale eddies forming in the lee and breaking off from the hill so as to be carried away down wind. The picture then is of very disturbed flow. In one case at any rate with a wind of 30 to 35 kt. (35–40 m.p.h.) blowing over a 150-ft. dune there were instantaneous vertical velocities of up to 700 ft./min. above the middle point of the lee slope. In another case in which a lee eddy was observed to break away from a dune about 120 ft. high, vertical velocities were observed of 120 to 150 ft./min. at distances of about 500 to 1,000 yd. from the foot of the dune. The intensity of the eddies usually decreases when they have travelled some miles from the hill, but there are no precise data on which to base an estimate of their rate of decay. Their intensity depends on the form and height of the hill : with mountains such as the Alps, the Atlas or the Appalachians they become very large and travel away as separate depressions with horizontal circulations.

If the airflow is steady, the downward velocity at any point near the surface is given by $V_0 \tan\alpha$ where α is the angle of slope of the hill, see Fig. 18. The downward velocity is greatest at the mid point of the hill slope. It is found empirically to be greatest a small distance above the ground surface ; at greater heights the down flow decreases rapidly.

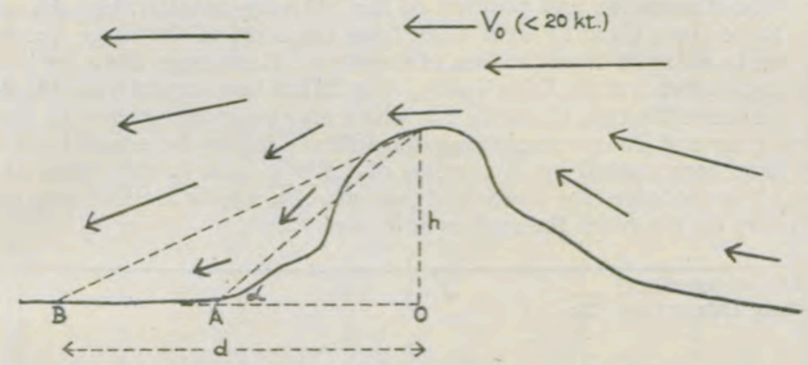

FIG. 18.—STEADY AIR FLOW OVER A RIDGE

The maximum down flow that can occur at a point B (Fig. 19) distant *d* from a hill of height *h* is V_0h/d provided the air flow is steady, without stationary eddies.

The vertical velocities generated by an isolated hill are much smaller than those generated by a ridge of hills over which the wind is blowing.

When winds are less than 20 kt. (23 m.p.h.) and the lapse rate is less than the dry adiabatic it is possible for stationary eddies to form both to leeward and to windward of the hills, see Fig. 19. It is seen that when such eddies occur the vertical current over point *X*, say, can be greater than V_0h/d.

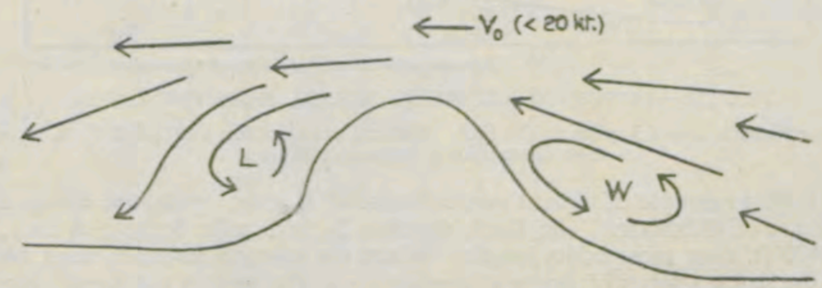

FIG. 19.—STEADY AIR FLOW OVER A RIDGE WITH STATIONARY WINDWARD (W) AND LEEWARD (L) EDDIES

As an example of the pattern which the vertical currents take in the lee of a mountain ridge the helm wind of the northern Pennines may be quoted, which has been examined by Manley[16] from whose paper the following is largely quoted. When a wind blows transverse to this range of mountains, which rises to between 2,000 and 3,000 ft., strong winds are observed down the leeward slope, and for varying distances across the lowlands below. In certain conditions these winds are greatly in excess of those which prevail over the country as a whole. The phenomena resemble those which occur at a submerged weir with inclined faces ; a " standing wave " is formed in the surface stream to leeward of the range. Vigorous downward and upward currents are formed. The clouds which accompany the helm wind are very striking. Over the top of the Pennines there extends a sheet of " helm cloud " but over the edge of the hills the downward curling and dissipation of the helm cloud is obvious. The extent to which the helm cloud juts to westward of the crest of the range appears to depend on the thickness of the cloud.

On occasion a separate roll (or rolls) of cloud becomes apparent, the " helm bar ". The dimensions and position of the bar vary considerably, the limits appear to be from three to eight miles from the crest of the range, i.e. from about one to six miles from the foot of the slope. Sometimes there are several bars extending out over the Eden Valley. Fig. 20 has been copied from Manley's paper ; it shows the type of circulation which may be encountered, and depicts the strong up and down current over the valley. It may be pointed out that gliders have been carried up in currents of 1,500 ft./min. in the region of the bar, and it is probable that downward currents of a similar amount may occur though they do not reach the surface with such speed.

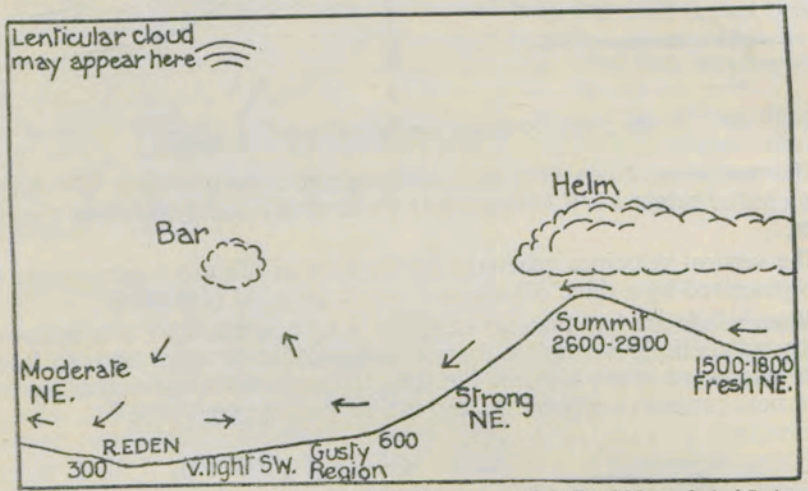

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FIG. 20.—SKETCH TO ILLUSTRATE NORMAL HELM PHENOMENA

Horizontal scale about 3 miles to the inch. Vertical exaggeration multiplied by 6. Arrows show characteristic behaviour of wind

Another example of violent vertical currents is given by the lee eddies near the Rock of Gibraltar. The Rock, which is $2\frac{1}{2}$ to 3 miles long, rises to 1,200 to 1,400 ft. over most of its length. When the easterly levanter wind blows over the Rock a series of strong eddies occurs to the west of the Rock over the Harbour. These eddies have given down currents and turbulence sufficient to cause accidents to aircraft in the past. Under these circumstances levanter clouds, very similar to the helm bar, occur down wind from the Rock. A survey[17] was made of the wind streams around the Rock by model and corroborated on the ground by pilot balloons. Seventy-seven pilot balloons showed that in easterly winds, mostly of about force 3 (10 kt. at ground level), there occurred 233 cases of well marked vertical components of air currents or changes in those components, with an average duration of $1\frac{1}{2}$ min. as the balloon passed upwards ; they were found at all heights up to 5,000 ft. and probably persisted higher still. Of currents exceeding 150 ft./min. there were 67 (42 down, 25 up), ranging up to maximum values of 680 and 760 ft./min. for down and up currents, respectively. It should be noted that (i) vertical currents of less duration than $1\frac{1}{2}$ min. could not be accurately measured; they were probably much in excess of these figures ; (ii) that downward vertical currents were much more common

To face page 50.

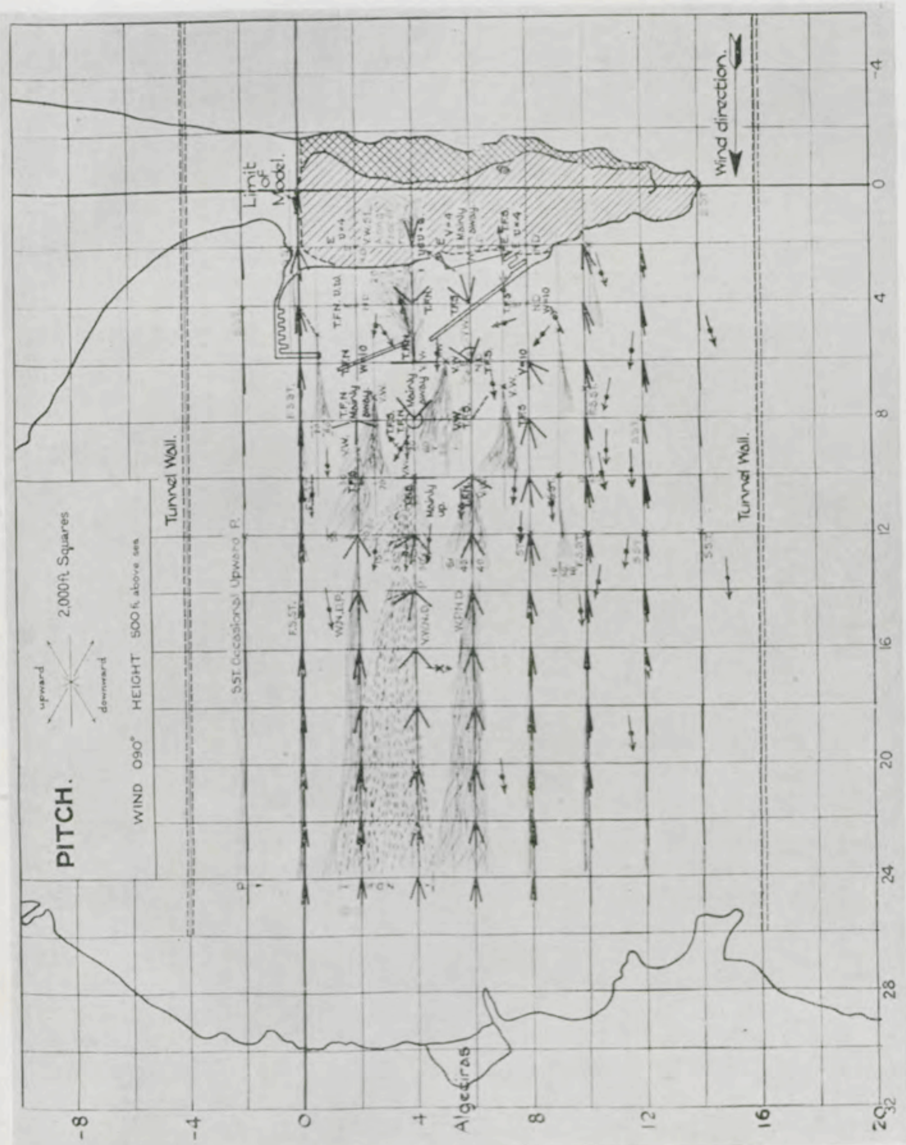

FIG. 21.—WIND FLOW AND FLUCTUATIONS AT 500 FT. AS SHOWN IN WIND TUNNEL
Diagram reproduced from " A survey of the air currents in the Bay of Gibraltar, 1929–30," by J. H. Field and R. Warden.

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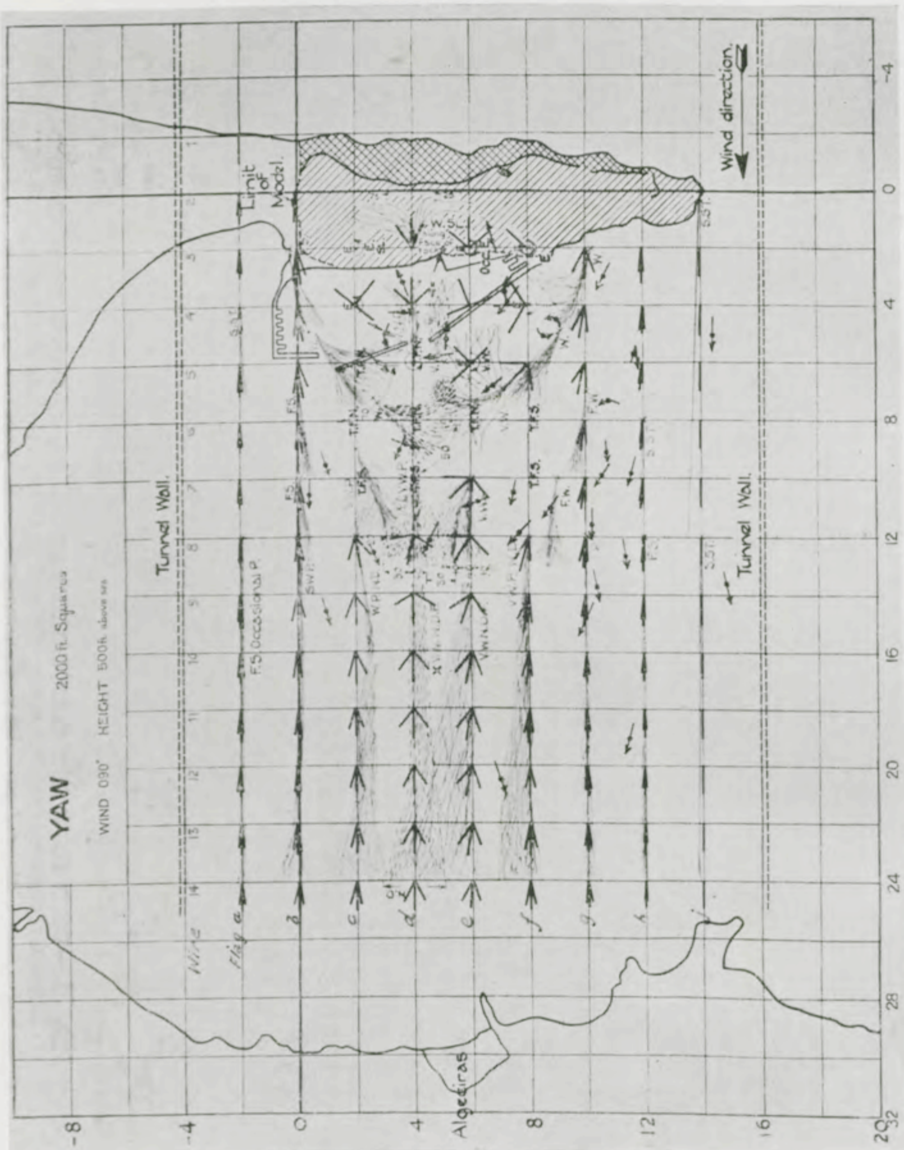

FIG. 22.—WIND FLOW AND FLUCTUATIONS AT 500 FT. AS SHOWN IN WIND TUNNEL. Diagram reproduced from "A survey of the air currents in the Bay of Gibraltar, 1929–30," by J. H. Field and R. Warden.

than upward currents ; and (iii) that with stronger winds the probability is that greater vertical currents would be formed, of the order of 1,500 ft./min.

In the wind tunnel, measurements of the direction of flow of the wind were made by means of silk threads (flags) pinned at various heights in fixed positions. The complexity of the resulting eddies is shown by the diagrams in Figs. 21 and 22 which give the wind flow and fluctuations at 500 ft. above sea level. Fig. 21 gives the pitch, Fig. 22 the yaw. In these diagrams there are three thicker lines in each position of observation; the central of these three lines shows the average flow, the other two the extremes, to the right and left in the case of yaw, up and down in the case of pitch. The letters printed on the diagram show the characteristics of the motion, for instance S. is steady, S.W. slightly wild, V.W. very wild. T.F.N. indicates the flag twisted round the cross tunnel attachment wire, i.e. there was a rotating eddy. Other diagrams on similar lines were constructed for other heights and other aspects. Fig. 22 show clearly how the wind swirls round the edge of an isolated hill such as the Rock of Gibraltar and clearly it cannot be considered as an infinite ridge. Fig. 21 shows up the violent vertical currents in the lee of the Rock.

The conclusion drawn from the work on Gibraltar was that with an obstacle of that type dangerous eddies would occur up to 2 miles down wind from the Rock, and at greater distances the air would be rough.

In view of the probability that landing and taking off will in future be possible for special types of aircraft in very confined localities mention must be made here of one or two types of local winds which would be of importance if attempts were made to land in rugged country. Among big mountain masses there occur very marked diurnal winds in deep valleys, which are quite unfamiliar to those whose knowledge is confined to hill country of 2,000 ft. or so.

Hillside winds, of the type known as anabatic and katabatic winds, are well known in all parts of the Alps. They blow up or down steeply sloping hillsides, so that their motion has always a large vertical component, either positive or negative.

The up-slope, or anabatic, wind blows during the time of sun heating, when the hillside is warm compared with the free air at the same level. The up-slope wind is of varying depth ; in the very deep major valleys (*e.g.* the Rhône Valley above Martigny, or the Engadine) it is from 800 to 2,000 ft. deep, with maximum speed about 400 or 500 ft. above the hillside. The speed parallel to the slope is generally no more than 9–13 kt. (10–15 m.p.h.) but rather greater speeds are sometimes reported from stations high up on the valley sides. The flow often merges into the vertical currents at the base of cumulus cloud forming above the slope. It is a common sight to see a small fluffy mass of cumulus creep up the valley wall as far as the break of slope, near the crest, and on account of this cloud Alpine guides regard the midsummer up-slope wind as a great danger to rock climbers. The up-slope wind is much used by sailplane pilots in gaining lift.

The down-slope, or katabatic, wind blows by night when radiational cooling lowers the temperature of the hillside below that of the free air at the same level. It is usually much shallower than the up-slope wind, but may be equally strong and gusty. Above the hill-slope wind there is a compensating current. By day only the up-slope wind is usually directly observed, but the existence of subsiding air in mid valley has been confirmed indirectly.

Shadow winds.—The maximum force of the up-slope (anabatic) wind comes shortly after the time of maximum solar heating. On a sloping mountain side this moment often differs from local noon, which is the time of zenith sun relative to a flat surface. In some valleys the slopes are so arranged that one slope receives much more solar heating than the other because of the shadow cast by the hills. The slope-wind system is then deranged, and becomes asymmetrical. The up-slope wind is confined to the sunny side, while on the shaded side a katabatic wind may blow all day.

Apart from the strongly developed winds mentioned above, katabatic winds are generally unlikely to be of major importance to the use of airfields, except in so far as their presence keeps the airfields clear of very low cloud and fog in such places as have moderately lofty hills inland, but that question is discussed in an earlier chapter.

§ 26. THE LAY-OUT OF RUNWAYS IN RELATION TO WIND

(*a*) *General problem.*—An airfield runway becomes unsafe for an aircraft landing on it when the wind blowing at right angles to the runway exceeds a critical value, as is seen in Fig. 23. If AO is the direction of the runway and BO the direction of the wind (V) which has a speed represented by the

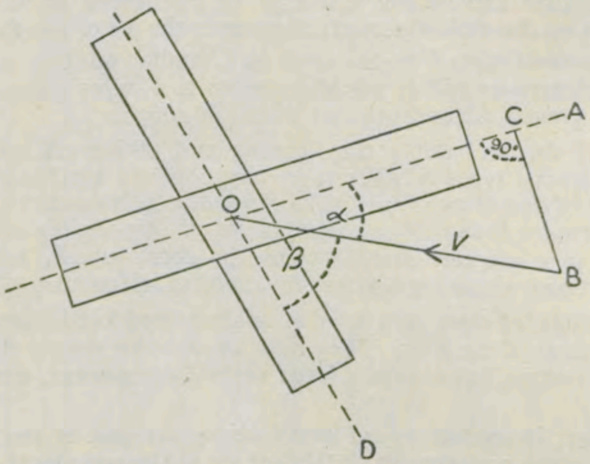

FIG. 23.—RUNWAY LAY-OUT IN RELATION TO WIND

length BO then the wind blowing at right angles to the runway (cross-wind component) is represented by BC or $V \sin \alpha$. If on the other hand the critical value of the cross-wind component (U) is known then clearly the critical wind speed for any given direction is given by :

$$V \sin \alpha = U$$

or

$$V = U \operatorname{cosec} \alpha$$

where α defines the direction.

If there are two runways and the wind blows at an angle α with one and β with the other, then the critical wind speeds are given by $V = U \operatorname{cosec} \alpha$ or $U \operatorname{cosec} \beta$ whichever is the less.

In Table XXVIII there are set out the critical values of V for various values of α.

TABLE XXVIII—VALUES OF V FOR VARIOUS VALUES OF U AND α

U \ α	10°	20°	30°	40°	50°	60°	70°	80°	90°
m.p.h.					miles per hour				
10	57	29	20	16	13	12	11	10	10
15	86	44	30	23	20	17	16	15	15
20	115	58	40	31	26	23	21	20	20

Note.—1 m.p.h. = 0·8684 kt.

It should be noted, however, that lower values of V than those given above may be associated with occasions on which gusts exceed the critical value. The magnitude of the ratio of gust to mean hourly wind speed varies according to topography, time of day and air mass, but as a rough working rule it may be said that the gusts do not frequently exceed twice the mean hourly wind speed ; so to allow for gusts one needs to divide the values in Table XXVIII by two. This allowance is not usually made in estimating the time lost on a proposed system of runways, but it is a figure which should be borne in mind.

In order to discuss the frequency with which an airfield is likely to be out of action (time loss) because the wind is too strong for landings, we require to know the frequency with which these critical values of V are exceeded for all wind directions.

The basic data on which the calculations have to be made are usually wind roses or tabulations of wind frequency such as that in Table XXIX, which shows the data available for Prestwick based on 3 years' observations. In this table, the wind directions are given to 16 points of the compass and wind speeds to each range of the Beaufort scale. Data such as these (based on, say, 10 years' observations) are sufficient to give the time loss accurately to about 0·1 per cent. Often, however, the only data available are arranged on a coarser pattern, both of direction and speed ; in those cases it is still possible to calculate time losses but the accuracy suffers.

The most direct method of calculating time losses is best explained by an example and for this we will take the actual example of Prestwick.

The main runway is in the direction 301°–121° and a secondary runway lies at 242°–62° (all directions are true). We will suppose that if the cross-wind component exceeds 13 kt. (15 m.p.h.) the runways cannot be used. Fig. 24 shows the lay-out, and clearly no wind can be at a greater angle than 60° with one or other of the runways. First, however, let us see how far the main runway is usable.

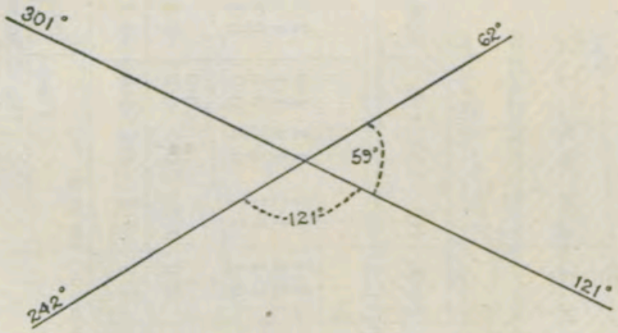

FIG. 24.—RUNWAY LAY-OUT AT PRESTWICK

From Table XXIX it is seen that 56 per cent. of winds are less than 11 kt. (13 m.p.h.) and 23 per cent. between 11 and 16 kt. (13 and 18 m.p.h.), i.e. about 68 per cent. are less than 13 kt. (15 m.p.h.) and for these the main runway will be used.

From Table XXIX we can form a fresh table giving the critical values of U for different actual wind directions at Prestwick.

Table XXX includes the secondary as well as the main runway, but brackets are put round those wind directions in which all possible landings would be made on the main runway.

TABLE XXIX—PERCENTAGE FREQUENCY OF WIND DIRECTION AND VELOCITY AT PRESTWICK, 1942 TO 1945

Lat. 55° 31′ N. Long. 04° 36′ W.

Height of vane or cups: above M.S.L. 72 ft.; above ground 40 ft.; above building 32 ft.; effective height 35 ft.

Mean wind speed				Percentage of hours recorded during the year from																
				NNE.	NE.	ENE.	E.	ESE.	SE.	SSE.	S.	SSW.	SW.	WSW.	W.	WNW.	NW.	NNW.	N.	All Directions
kt.	m.p.h.	ft./sec.	m./sec.	per cent.																
<1	<1	≤2	<0·3																	} 13·8
1–3	1–3	3–5	0·3– 1·5																	
4–6	4–7	6–11	1·6– 3·3	0·7	1·2	1·5	1·9	2·3	2·0	1·4	1·0	0·7	0·8	1·1	1·2	0·9	0·7	0·7	0·4	18·5
7–10	8–12	12–18	3·4– 5·4	0·4	1·2	1·9	1·1	1·2	1·3	1·5	2·1	2·1	2·4	2·4	1·7	1·6	1·2	0·8	0·5	23·4
11–16	13–18	19–27	5·5– 7·9	0·2	0·7	1·1	0·8	0·6	0·5	1·0	2·0	2·7	2·9	3·3	2·4	2·4	1·5	0·7	0·5	23·3
17–21	19–24	28–36	8·0–10·7	0·1	0·1	0·1	0·2	0·1	0·1	0·3	0·8	1·7	2·4	2·4	1·7	1·4	0·8	0·3	0·2	12·7
22–27	25–31	37–46	10·8–13·8	–	–	–	–	–	–	0·1	0·3	0·8	1·1	1·4	1·0	0·8	0·5	0·1	0·1	6·2
28–33	32–38	47–56	13·9–17·1	–	–	–	0·0	–	–	0·0	–	0·1	0·2	0·3	0·3	0·2	0·1	0·0	–	1·2
34–40	39–46	57–68	17·2–20·7	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·0	0·1	–	–	7	–	–	0·0	0·1
≥4	≥4	≥6	≥1·6	1·4	3·2	4·6	4·0	4·2	3·9	4·3	6·2	8·1	9·9	10·9	8·3	7·3	4·8	2·6	1·7	85·4

A dash indicates less than 0·1 per cent.

Total under 4 kt. (4 m.p.h.)	13·8
Total ≥4 kt. (4 m.p.h.)	85·4
No. of hours missed	0·8
Total	100·0

TABLE XXX—CRITICAL VALUES OF WIND SPEED FOR VARIOUS WIND DIRECTIONS AT PRESTWICK

Main runway

Wind direction	301°	131° 291° 311° 111°	141° 281° 321° 101°	151° 271° 331° 91°	161° 261° 341° 81°	171° 251° 351° 71°	181° 241° 1° 61°	191° 231° 11° 51°	201° 221° 21° 41°	211° 31°
	121°									
Critical speeds (miles per hour)	∞	86	44	30	23	20	17	16	15	15

Secondary runway

Wind direction	242°	72° 232° 252° 52°	82° 222° 262° 42°	(92°) 212° (272°) 32°	(102°) 202° (282°) 22°	(112°) 192° (292°) 12°	(122°) (182°) (302°) (2°)	(132°) (172°) (312°) (352°)	(142°) (162°) (322°) (342°)	(152°) (332°)
	62°									
Critical speeds (miles per hour)	∞	86	44	30	23	20	17	16	15	15

Note.—1 m.p.h. = 0·8684 kt.

In Fig. 25 these values have been plotted against the angle and curves have been drawn through the points. The diagram then shows the winds by speed and direction which can and cannot be used. To bring this out the parts of the diagram in which winds can be used for landings are hatched. The parts where landings cannot be made are left blank. On this diagram there are inserted in the appropriate positions the frequencies per thousand derived from Table XXV. Then, by inspection of areas it is possible to obtain a sum of the frequencies with which landings are impossible, or are possible only on the secondary runway. The results are about 3 per cent. of occasions when no landing is possible, and 13½ per cent. when landings are only possible on the secondary runway. So that the main runway can be used on about 84 per cent. of occasions.

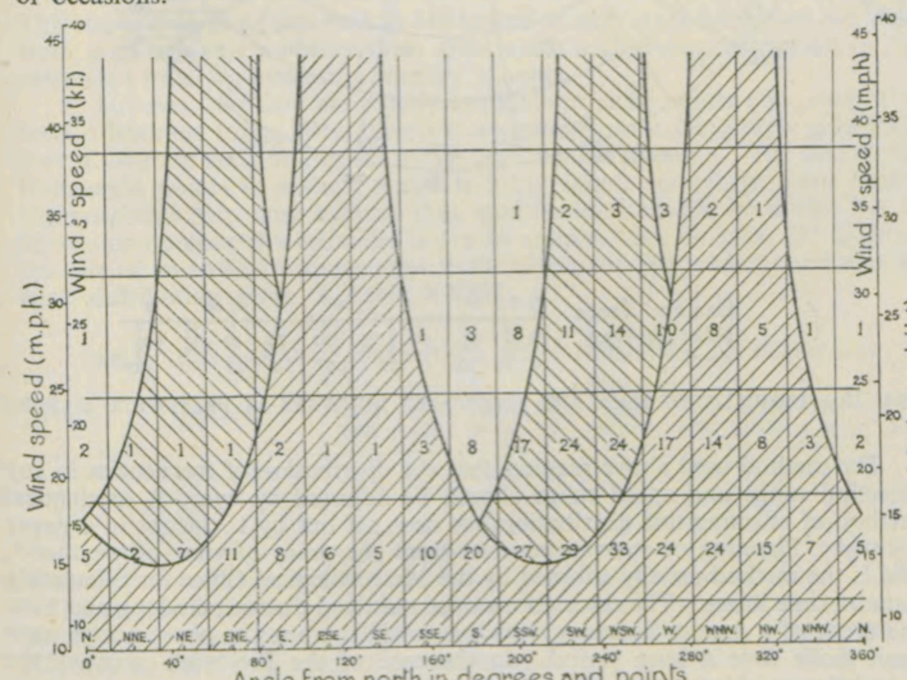

FIG. 25.—FREQUENCY WITH WHICH MAIN AND SECONDARY RUNWAYS CAN BE USED AT PRESTWICK AIRPORT

It may be desired to carry out such computations on a polar diagram, as shown in Fig. 26 ; here, the hatched areas again correspond with the winds which can be used for landings, and the clear areas with those winds which give a cross component on the runways exceeding 13 kt. (15 m.p.h.).

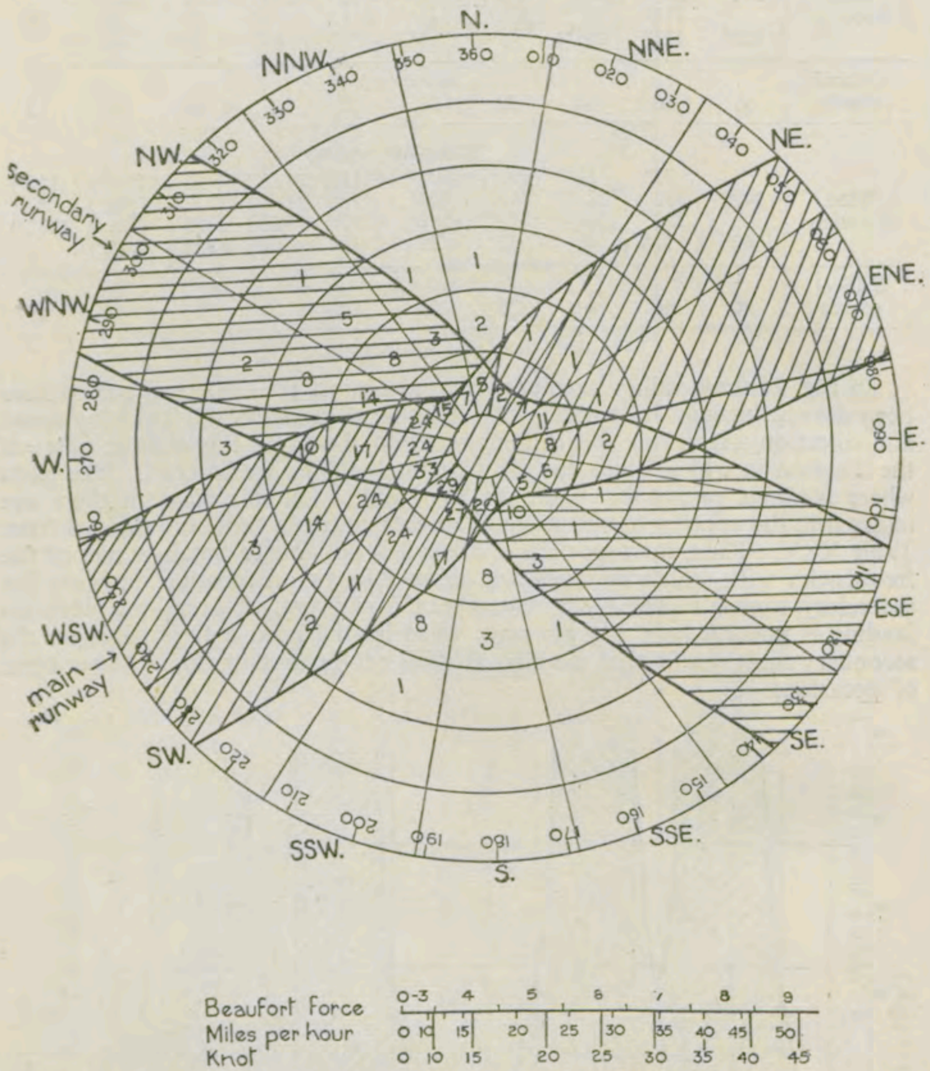

FIG. 26.—USABILITY OF MAIN AND SECONDARY RUNWAYS AT PRESTWICK AIRPORT

The method used above requires that the distribution of frequencies in any direction range and speed range should be adjusted by eye. A mechanical method of effecting this distribution has been set out by L. Jacobs in a paper entitled " Planning of runway lay-outs from the point of view of weather ", and is the method usually adopted by the Meteorological Office for calculating data on time losses. The calculations once mastered do not take long and have the merit of a greater accuracy, which is justified when the observations have been made over a long period. In the case of the Prestwick runways the calculations yielded a time loss of 3·4 per cent.

The graphical method set out above is eminently suited to the planning of the best combination of runways, if the curves representing 15 cosec α are drawn on celluloid for placing over the diagram of wind frequencies shown in Fig. 25, then, by moving the celluloid sheets one over the other and over the diagram it is possible by trial and error to find the directions of the best orientated runways, though of course, in practice physical features may compel modifications to be made.

It is well to add the values of N. to S., NNE. to SSW., NE. to SW. and so on as that will reduce the number of interpolations which have to be made and thereby materially speed up the computations.

(*b*) *Case of deficient data.*—It is often necessary to design runways with few or no data, and so it is well to set out what can be done in those circumstances.

First, as regards the accuracy of a representation derived from a short period of observation, individual years can be compared with a combination of years at a station at which an anemometer has been in operation for a long time. This has been done for Mildenhall where the runways lie at the angles 45°, 90°, and 135°. The result is shown in Table XXXI.

TABLE XXXI—PERCENTAGE TIME LOSS AT MILDENHALL DURING VARIOUS PERIODS DUE TO WINDS EXCEEDING 13 KT. (15 M.P.H.) CROSS-COMPONENT AND TO GUSTS EXCEEDING 13 KT. (15 M.P.H.) CROSS-COMPONENTS

Period	Time loss	Time loss due to gusts
	per cent.	
1940 (1 yr.)	0·39	5·9
1941 (1 yr.)	0·36	5·5
1942 (1 yr.)	0·44	6·4
1940–42 (3 yr.)	0·38	5·9
1937–43 (7 yr.)	0·43	6·4

This shows that, in a place such as Mildenhall at any rate the time loss calculated from even one year's observations gives quite a close approximation to that calculated from the mean of a number of years.

If, however, the data are readily available to eight points only, and/or for certain Beaufort forces only, then it is necessary to distribute them graphically over a diagram such as Fig. 25 in the best manner possible. The distribution from eight points to sixteen points is fairly simple though in some cases a topographical map may indicate that modifications should be made, but the distribution among the velocities is not so simple. Let us take, for example, the case of an airfield with runways in the directions 360° and 45° and with the wind distribution given in Table XXXII.

TABLE XXXII—ANNUAL PERCENTAGE WIND FREQUENCY AT HELIOPOLIS

Force	Speed		Direction								Calm
			NNE. SSW.	NE. SW.	ENE. WSW.	E. W.	ESE. WNW.	SE. NW.	SSE. NNW.	S. N.	
	kt.	m.p.h.									
1–3	1–10	1–12	11·9	10·5	5·7	7·2	7·0	8·7	10·4	18·4	6·4
4–5	11–21	13–24	2·7	2·5	1·6	1·1	0·6	0·7	0·6	3·1	
6–7	22–23	25–38	0·1	0	0·1	0	0	0	0	0·1	
Total ..	..	..	14·7	13·0	7·4	8·3	7·6	9·4	11·0	21·5	6·4

From this table we know for instance that winds exceed 1 kt. (1 m.p.h.) on 14·7 per cent. of occasions from NNE. or SSW. and exceed 10½ kt. (12½ m.p.h.) on 2·8 per cent. of occasions while they exceed 21½ kt. (24½ m.p.h.) on only 0·1 per cent. of occasions.

If we plot these points on squared paper as is done in Fig. 27 it is hard to draw a fair curve through the points other than that shown. From this we can read off the frequency of winds exceeding any desired amount, *e.g.* U cosec α. If similar curves are drawn for each direction we can get directly the time loss. In the particular case cited above there would be no time loss on the pair of runways for hourly mean winds with cross components more than 13 kt. (15 m.p.h.), but for gusts of 13 kt. (15 m.p.h.) cross component the time loss would be about 3 per cent.

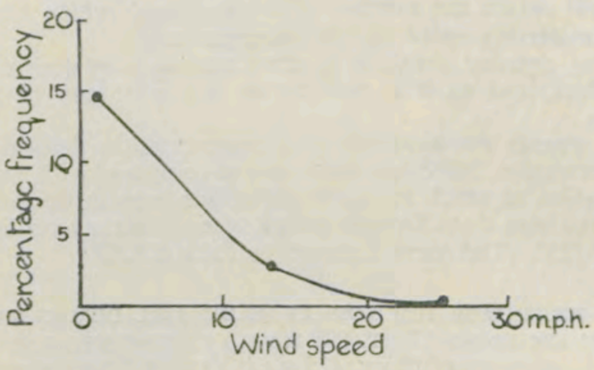

FIG. 27.—PERCENTAGE FREQUENCY OF WINDS EXCEEDING CERTAIN SPEEDS FROM NNE. OR SSW. AT HELIOPOLIS

Where no data are available for the airfield itself it may be possible to adjust the values obtained from a neighbouring station to suit the topography of the surroundings of the airfield, but for that no general rules can be given. It is a matter for the expert.

In many parts of the world winds are so rarely fresh or strong that the consideration of wind in the siting of runways is of secondary importance in comparison with other factors, but expert meteorological advice is generally necessary on any site before the final decision is made regarding the lay-out.

CHAPTER VI

PRESSURE AND TEMPERATURE

§ 27. GENERAL

For the determination of the necessary length of runway to enable a given aircraft to take off with a given load the air temperature and pressure at the level of the airfield are required. If the maximum temperature that is likely to be encountered and the associated pressure at the level of the runway are given, a value of the minimum density can be calculated which governs the distance of run before take-off, provided that the engines are working at a given capacity. The efficiency of the engines is dependent, however, on the temperature of the air, and hence the minimum density is not all that is required and the data are most conveniently given in temperature and pressure.

Different engines, however, would require different weighting factors so that every combination of engine and aircraft would need a separate calculation to state what runway length would be necessary. It may be then that for simplicity an approximate rule of thumb dependent on the minimum density at the airfield is all that is required. The form of the allowance necessary to the runway length for variation in pressure and temperature is not yet decided internationally, but it is almost certain to take the form of conversion factors by which the standard length of runway for any particular aircraft has to be multiplied to allow for pressure and temperature.

If no regard is paid to engine performance we can take the conversion factor to be 1·15 per cent. increase in take-off runway length for every 1 per cent. decrease in density.

§ 28. USE OF METEOROLOGICAL DATA

(*a*) *Type of data required and available.*—Clearly the designer requires to know the extreme conversion factor, and if possible the frequency of occurrence of various conversion factors for thereby he can assess a balance between the expense of lengthy runways and their efficiency in use. The meteorologist is called on therefore to provide data in two forms, namely, first a world survey of extreme temperature and associated pressure by which the designer can see rapidly the worst conditions with which he will probably have to contend at any place at the appropriate height above sea level, and secondly, a means of calculating the frequency of occurrence of various conversion factors.

(*b*) *Geographical distribution of maximum temperatures and associated pressures.*—Fig. 28 is a map of the world giving the probable maximum temperature which will occur at any place during a given twelve months. This does not mean that in no year is the value exceeded, but if one took a year at random it is as likely that the maximum temperature recorded at any time in that year would be below the appropriate figure read off the map as that it would be above that figure. In general, these extreme temperature values may be taken to apply to airfields at the general level of the country at the point shown, especially on plains and in plateau regions. Isolated high hills or mountains will have lower maxima than plateaux at the same level, the difference depending on the topography.

Fig. 29 is a map showing the most likely pressure to be associated with the maximum temperature read off Fig. 28. It is not a map of pressure in any particular month, since the pressures have been especially chosen to combine with the maximum temperatures.

Pressure, however, decreases rapidly with height and this map is reduced to sea level. A correction, accordingly, has to be made for the height of the airfield. The accuracy of the data does not warrant these calculations of pressure being made in great detail, but the corrections given below are sufficiently close for the design of runways.

Table XXXIII shows the estimated pressure at heights of 1,000, 2,000 up to 11,000 ft., when the surface pressure is 1012 mb. and the maximum temperature read off the map is that shown at the head of the column. It is based on the average relation between the mean annual maximum temperature (Fig. 28) and the mean temperature of the warmest month and the vertical decrease of temperature on very hot days at Habbaniyah and Khartoum.

TABLE XXXIII—PRESSURE AT DIFFERENT HEIGHTS

Height	Mean annual maximum temperature, °F.							
	50°	60°	70°	80°	90°	100°	110°	120°
ft.	*millibars*							
11,000	651	656	661	665	670	675	680	685
10,000	679	683	688	693	697	702	706	711
9,000	708	712	717	721	725	729	733	737
8,000	738	742	746	750	754	757	761	765
7,000	769	772	776	779	783	787	790	793
6,000	801	804	807	810	813	816	819	822
5,000	833	836	839	842	844	847	849	852
4,000	867	870	872	874	876	878	880	882
3,000	902	904	906	907	909	911	912	914
2,000	938	939	941	942	943	944	945	946
1,000	975	975	976	977	978	978	978	979
0	1012	1012	1012	1012	1012	1012	1012	1012

To use the table, read off the mean annual maximum temperature from Fig. 28 to the nearest 5° F. Then find the height of the airfield to the nearest hundred feet, read off the corresponding pressure in the table at heights of exact thousands of feet above and below this height and interpolate between them. For example :—

Height of airfield : 6,426 ft., or 6,400 to nearest 100 ft.

Mean annual maximum temperature from Fig. 28 : 95° F. At 6,000 ft. pressure for 90° and 100° F. are 813 mb. and 816 mb., mean 815 mb. At 7,000 ft. pressure for 90° and 100° F. are 783 mb. and 787 mb., mean 785 mb. Subtracting four tenths of the difference of 30 mb. from the pressure at 6,000 ft. we obtain 815—12 or 803 mb.

If the pressure at M.S.L., read off Fig. 29, differs from 1012 mb. by 5 mb. or more, the computed pressure at the airfield should be multiplied by the M.S.L. pressure and divided by 1012, but this correction is not worth while for sea-level pressure between 1007 and 1017 mb.

Table XXXIV gives some further examples of the calculation of the probable maximum annual temperature and associated pressure for various places.

Before going further, some justification is needed for the use of the maximum temperature and associated pressure in deriving the minimum density rather than the minimum pressure and associated temperature.

Apart from regions affected by tropical revolving storms the parts of the earth where the sea-level pressure variations are most likely to outweigh the temperature variations, are the cyclonic belts from Newfoundland to Iceland and northern Norway and the Japanese Islands to Alaska. These regions have been examined in detail, and it has been found that the density calculated from the actual readings of air temperature and pressure was very rarely less than the

To face page 60.

FIG. 28.—AVERAGE ANNUAL MAXIMUM TEMPERATURE (IN DEGREES FAHRENHEIT)

To face page 61.

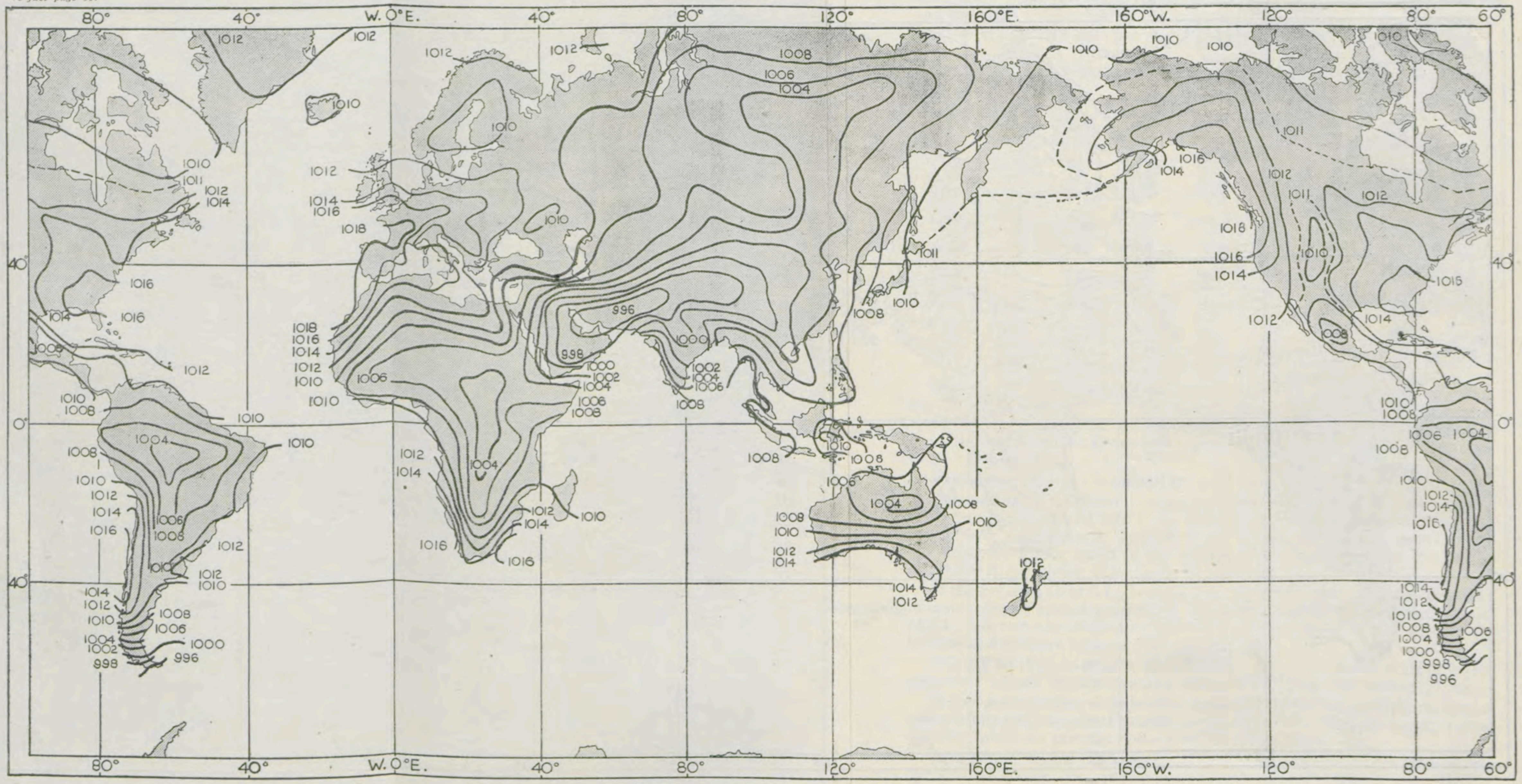

FIG. 29.—AVERAGE PRESSURE (IN MILLIBARS) AT MEAN SEA LEVEL OF THE MONTH WITH HIGHEST AVERAGE MAXIMUM TEMPERATURE
Corrected in the tropics for diurnal variation to the afternoon value

TABLE XXXIV—PROBABLE MAXIMUM TEMPERATURES AND ASSOCIATED PRESSURES

	Height above M.S.L.	Probable maximum temperature	Probable associated pressure at M.S.L.	Correction for height	Probable associated pressure at airfield
	ft.	°F.	mb.	mb.	mb.
Rome (Ciampino) ..	380	95	1014	—14	1000
Cairo (Almaza) ..	72	110	1009	— 3	1006
Karachi (Mauripur) ..	55	100	1008	— 3	1005
Johannesburg (Germiston)	5,448	100	1010*	—12	835

* At Johannesburg the probable associated pressure at 5,000 ft. is 847 mb.

minimum density deduced by taking the maximum temperature for the appropriate place from Fig. 28 and the associated pressure from Fig. 29. The cases in which the actual densities were lower than those derived from the maps may be considered as the abnormalities with which the maps are not designed to cope. The same may be said of the extremes of pressure in tropical revolving storms, since the chance of such a meteor striking a place, even one in the most frequented area, is very small. In addition during the height of tropical revolving storms the weather is so bad that flying operations would probably be cancelled in any case.

(c) *Frequency of various pressure-temperature combinations.*—To show the relative frequency of various combinations of pressure and temperature a count was made of occasions at Croydon with various temperatures at 1300 G.M.T. and the associated pressures, the result is shown in Table XXXV.

TABLE XXXV—AVERAGE NUMBER OF OCCASIONS PER ANNUM WITH VARIOUS TEMPERATURES AT 1300 G.M.T. AT CROYDON AND THE ASSOCIATED PRESSURES

CROYDON 51° 21′ N., 0° 07′ W., 225 ft. Period 1936 to 1940*

Pressure at M.S.L.	Temperature in °F. 21° to 25°	26° to 30°	31° to 35°	36° to 40°	41° to 45°	46° to 50°	51° to 55°	56° to 60°	61° to 65°	66° to 70°	71° to 75°	76° to 80°	81° to 85°	86° to 90°	Total
mb.															
976–80	0	0	0·2	0·2	0·2	0·2	0·4	0	0	0	0	0	0	0	1
981–85	0	0	0·2	0·2	0·8	1	0·6	0·2	0	0	0	0	0	0	3
986–90	0	0	0·2	0·6	1	3	1	0·2	0·2	0	0	0	0	0	6
991–95	0	0·2	1	1	2	3	2	0·6	0·2	0	0	0	0	0	10
996–1000	0	0·2	1	1	2	5	4	3	1	0·2	0·2	0	0	0	18
1001–05	0	0·2	0·8	1	3	5	7	3	2	1	0	0	0·2	0	23
1006–10	0·2	0·4	1	2	5	5	7	9	10	4	2	0·6	0·4	0	47
1011–15	0	0·6	1	3	4	11	9	11	14	10	5	2	0·6	0	71
1016–20	0·2	0·6	2	4	6	9	10	10	11	12	8	3	0·2	0·2	76
1021–25	0	2	3	4	6	8	6	9	10	7	5	4	0·8	0	65
1026–30	0	0·4	1	2	3	4	4	3	4	3	3	0·2	0	0	28
1031–35	0	0	1	2	3	3	2	1	1	0·2	0	0	0	0	13
1036–40	0	0	0·2	0·6	1	0·6	0·6	0·8	0	0	0	0	0	0	4
1041–45	0	0	0	0	0	0	0·2	0	0	0	0	0	0	0	0·2
Total ..	0·4	5	13	22	37	58	54	51	53	37	23	10	2	0·2	365

* In August and September 1940 observations were occasionally interrupted and so the month s August and September 1941 were substituted.

For comparison similar tables have been prepared for Kabete as representing a high-level station in the tropics and Khartoum.

These tables bring out the great contrast in variability of both pressure and temperature (particularly the former) between the equatorial and the temperate regions.

TABLE XXXVI—NUMBER OF OCCASIONS WITH VARIOUS TEMPERATURES AND THE ASSOCIATED PRESSURES AT 1300 ZONE TIME

KABETE 1° 16′ S., 36° 48′ E., 6,004 ft. Period 1931

Pressure at station level	Temperature in ° F. 56° to 60°	61° to 65°	66° to 70°	71° to 75°	76° to 80°	81° to 85°	Total
mb.							
816–20	—	1	27	54	18	2	102
821–25	5	34	88	110	26	—	263
Total	5	35	115	164	44	2	365

TABLE XXXVII—AVERAGE NUMBER OF OCCASIONS PER ANNUM WITH VARIOUS TEMPERATURES AND THE ASSOCIATED PRESSURES AT 1400 EGYPTIAN STANDARD TIME

KHARTOUM 15° 37′ N., 32° 33′ E., 1,280 ft. Period 1934 to 1938

Pressure at station level	Temperature in °F. 76° to 80°	81° to 85°	86° to 90°	91° to 95°	96° to 100°	101° to 105°	106° to 110°	111° to 115°	Total
mb.									
956–60	0	0	0	0	1	2	7	6	16
961–65	1	1	12	36	70	93	34	8	255
966–70	2	14	27	29	15	4	0·2	0	91
971–75	2	1	0·2	0	0	0	0	0	3
Total	5	16	39	65	86	99	41	14	365

From such tables as these it is a simple matter to arrange a frequency diagram of conversion factors, but such comprehensive data are not usually available without a lot of extraction from individual records. More often the data of mean monthly maximum temperature and mean daily maximum temperature are available. By the former term is meant the mean of the *n* maximum temperatures observed in each of the *n* months (of March say) in *n* years. This represents a chance of occurrence of about 4 in a hundred occasions (4 percentile). By mean daily maximum temperature is meant the mean of every day's highest temperature throughout the month in a succession of years and represents a chance of one in two that it will be exceeded on any day, " the mode ". In some cases instead of the mean daily maximum temperature the only available data are the mean temperatures at an hour or two hours after noon (local time). These data can be used by an expert statistician for obtaining an approximation to the distribution of daily maximum temperatures.

As regards pressure it may be assumed in the first place that the associated pressure is constant for the month under discussion and has the mean value at the hour of say 1400 local time. The map in Fig. 29 gives a representation of this value of pressure during the hottest month of the year. Alternatively, for other months the average pressure throughout the day can be taken and adjusted to 1400 local time by subtracting values ranging from 0·1 mb. for temperate latitudes to 1·5 mb. for tropical latitudes.

§ 29. FREQUENCY OF CONVERSION FACTORS

When the distribution of temperature and associated pressure has been determined we can calculate the frequency of various conversion factors according to whatever law is decided. As an example may be quoted the following which is based on what is called the B.O.A.C. formula. At Khartoum in April the adjusted pressure is 963 mb., and by using this value and the temperature deduced from the mean monthly maximum temperature in April and the corresponding mean daily maximum we get the following table.

TABLE XXXVIII—PERCENTAGE OF DAYS WITH VARIOUS CONVERSION FACTORS AT KHARTOUM IN APRIL

Conversion factor	1·38	1·37	1·36	1·35	1·34	1·33	1·32	1·31	1·30	1·29	1·28	1·27	1·26
Percentage of days on which factor is likely to be exceeded	0·9	2·5	6	12	22	35	50	65	78	88	94	97·5	99·1

In extratropical latitudes, however, there is a very much bigger variation of temperature, but even so when tested for Croydon the error involved in using a fixed value of pressure does not make a very great difference except for a few days with low conversion factors. In particular it was seen that for the lower range of frequencies, up to about 50 days a year the conversion factors based on these approximations differ by a little more than 0·01 and it is this part of the curve which is of the greatest interest to airfield designers.

In illustration, a list of conversion factors based on the B.O.A.C. formula for a selection of airfields is given in Appendix IV.

§ 30. FREQUENCY OF VARIOUS DENSITIES

To complete the picture there are set out in Tables XXXIX, XL and XLI, the frequencies of different densities at station level at Croydon, Kabete and Karachi.*

TABLE XL—FREQUENCY OF DIFFERENT STATION LEVEL DENSITIES, KABETE, 1300 ZONE TIME

KABETE 1° 16′ S., 36° 48′ E., 6,004 ft. Period 1931

gm./m³	Density range 941 to 950	951 to 960	961 to 970	971 to 980	981 to 990	991 to 1,000	1,000 to 1,010
Slugs × 10³	1·84	1·85	1·87	1·89	1·91	1·93	1·95
January	—	7	22	2	—	—	—
February	1	9	14	3	1	—	—
March	—	2	24	4	—	1	—
April	—	—	24	5	1	—	—
May	—	—	10	17	4	—	—
June	—	—	1	12	13	4	—
July	—	—	3	18	8	1	1
August	—	—	5	11	9	6	—
September.. ..	—	2	10	12	4	2	—
October	—	2	21	7	1	—	—
November.. ..	—	2	15	12	1	—	—
December ..	—	—	16	14	1	—	—
Year	1	24	165	117	43	14	1

* The normal density of the atmosphere at sea level is 1226 gm./m³ or 0·002378 slugs, *i.e.* 1gm./m³ = 1·94. 10^6 slugs or 1 slug = 5·15. 10^5 gm./m³.

TABLE XXXIX—FREQUENCY OF DIFFERENT M.S.L. DENSITIES, CROYDON, 1300 G.M.T.

CROYDON 51° 21′ N., 0° 07′ W., 225 ft. Period 1936 to 1940

gm./m.³	Density Range 1,161 to 1,170	1,171 to 1,180	1,181 to 1,190	1,191 to 1,200	1,201 to 1,210	1,211 to 1,220	1,221 to 1,230	1,231 to 1,240	1,241 to 1,250	1,251 to 1,260	1,261 to 1,270	1,271 to 1,280	1,281 to 1,290	1,291 to 1,300	1,301 to 1,310	1,311 to 1,320	1,321 to 1,330
Slugs × 10^3	2·26	2·28	2·30	2·32	2·34	2·35	2·37	2·39	2·41	2·43	2·45	2·47	2·49	2·51	2·53	2·55	2·57
January	—	—	—	—	0·2	2	2	5	3	5	3	4	3	2	1	1	0·6
February ..	—	—	—	—	0·4	0·6	2	1	4	7	4	2	3	3	0·4	0·6	—
March	—	—	—	—	0·4	2	3	4	5	6	3	4	2	0·6	—	—	—
April	—	—	0·2	0·4	0·8	3	3	6	5	5	5	2	0·2	—	—	—	—
May	—	0·4	0·4	2	3	6	6	7	4	2	0·8	—	—	—	—	—	—
June	0·4	0·4	1	4	7	8	5	4	0·4	—	—	—	—	—	—	—	—
July	—	0·4	1	5	10	9	5	1	—	—	—	—	—	—	—	—	—
August	0·2	1	2	6	9	9	3	0·6	0·2	—	—	—	—	—	—	—	—
September ..	—	—	0·2	5	5	7	5	5	3	0·4	—	—	—	—	—	—	—
October	—	—	—	0·8	0·8	5	5	6	6	5	2	—	—	—	—	—	—
November ..	—	—	—	0·2	1	3	3	4	5	5	2	3	2	1	0·2	—	—
December ..	—	—	—	—	—	0·8	2	2	3	4	4	2	3	6	3	0·8	0·2
Year ..	0·6	2	5	23	38	55	44	46	39	39	24	17	13	13	5	2	0·8

TABLE XLI—FREQUENCY OF DIFFERENT M.S.L. DENSITIES, KARACHI (MANORA), 1800 I.S.T.

KARACHI (MANORA) 24° 48′ N., 66° 39′ E., 13 ft. Period 1944 to 1945

gm./m.³	Density range 1,111 to 1,120	1,121 to 1,130	1,131 to 1,140	1,141 to 1,150	1,151 to 1,160	1,161 to 1,170	1,171 to 1,180	1,181 to 1,190	1,191 to 1,200	1,201 to 1,210	1,211 to 1,220	1,221 to 1,230
Slugs × 10^3	2·16	2·18	2·20	2·22	2·24	2·26	2·28	2·30	2·32	2·34	2·35	2·37
January	—	—	—	—	—	—	1	9	14	5	1	1
February	—	—	—	—	—	—	5	15	7	—	1	—
March ..	—	—	—	1	1	8	17	3	—	1	—	—
April ..	—	—	0·5	—	5	15	9	0·5	—	—	—	—
May ..	—	—	1	9	16	4	1	—	—	—	—	—
June ..	—	—	14	15	1	—	—	—	—	—	—	—
July ..	0·5	0·5	8	14	7	1	—	—	—	—	—	—
August ..	—	0·5	1	13	14	2	0·5	—	—	—	—	—
September	—	—	—	—	21	9	—	—	—	—	—	—
October	—	—	—	1	9	14	7	—	—	—	—	—
November	—	—	—	1	1	14	13	1	—	—	—	—
December	—	—	—	—	—	2	7	10	11	1	—	—
Year	0·5	1	24·5	54	75	69	60·5	38·5	32	7	2	·1

The density of air is given by the formula

$$\varrho = \frac{p}{RT}\left(1 - \frac{3}{8}\frac{e}{p}\right)$$

where ϱ is density, p is pressure, e is the portion of the total pressure due to water vapour, T is temperature in absolute degrees and R is the gas constant.

The values of density given in the nomogram shown in Fig. 30 are those obtained from the formula $\varrho = p/RT$ (*i.e.* neglecting the effect of vapour pressure) and the same is true of the other values quoted above.

The values of saturation vapour pressure for various temperatures are given in Table XLII.

TABLE XLII—SATURATION VAPOUR PRESSURE (OVER WATER) FOR AIR AT VARIOUS TEMPERATURES AND DENSITIES AT A BAROMETRIC PRESSURE OF 1000 MB.

Temperature (°F.)	30°	40°	50°	60°	70°	80°	90°	100°	110°	120°
Vapour pressure (mb.)	5·6	8·4	12·3	17·7	25·1	35·0	48·2	65·5	88·0	116·7
Density at a pressure of 1000 mb. with dry air (gm./m.³) ..	1,282	1,257	1,233	1,207	1,185	1,164	1,142	1,121	1,101	1,083
Density at a pressure of 1000 mb. with saturated air (gm./m.³) ..	1,280	1,253	1,227	1,199	1,174	1,149	1,121	1,093	1,065	1,035
Difference (gm./m.³) ..	2	4	6	8	11	15	21	28	36	48
(slugs × 10^3) ..	0·4	0·8	1·2	1·6	2·1	2·9	4·1	5·4	7·0	9·2

If the air is not saturated the decrease in density is proportional to the relative humidity so that for example air at 70° F. with relative humidity of 60 per cent. has a density of 1,178 gm./m.³ when at 1000 mb. pressure.

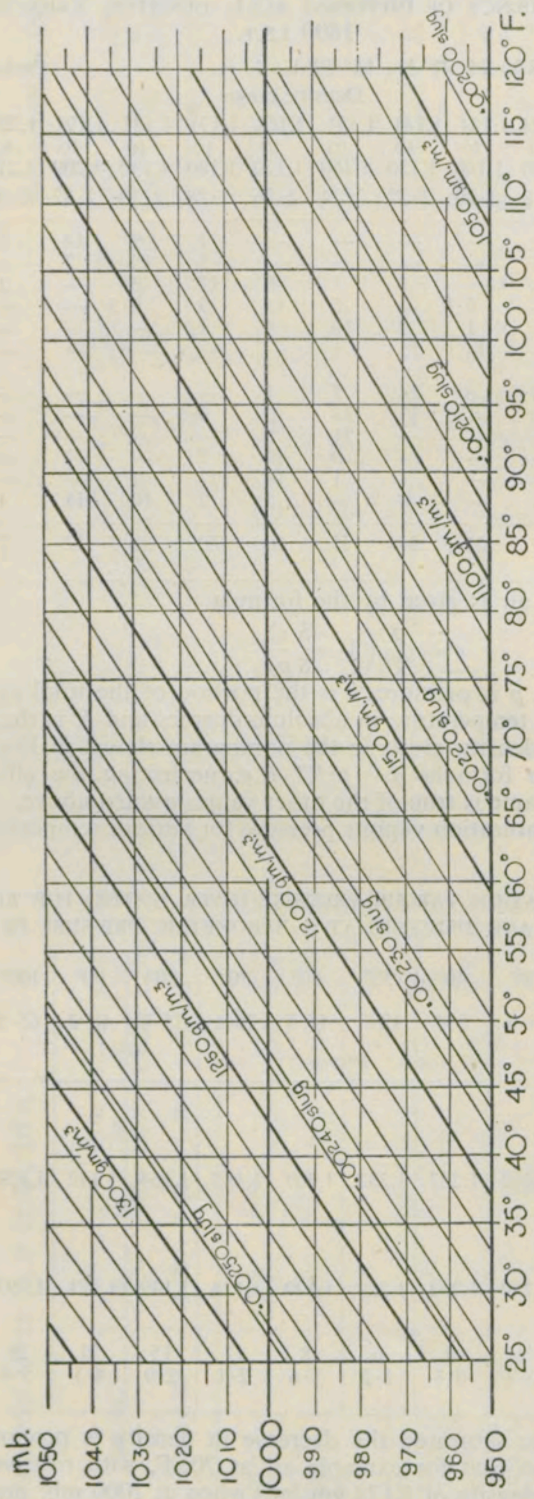

FIG. 30.—ISOPLETHS FOR OBTAINING THE DENSITY OF DRY AIR FROM VALUES OF PRESSURE AND TEMPERATURE

Clearly the error in the calculation of density from Fig. 30 due to the presence of water vapour is only important when the temperature is high.

In general, saturated air at 85° F. is uncommon and at 90° F. is rare. Usually, when the temperature is very high the air is relatively dry, since in many cases the high temperature is due to diurnal heating or to a foehn effect. Hence, even in the worst case, the density is not likely to be in error by more than 1 or 2 per cent. if the air is assumed to be dry.

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APPENDIX I

AVERAGE NUMBER OF DAYS WITH VISIBILITY LESS THAN 2½ MILES

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
Greenland ..	Bluie West ..	Narsarssuak	61° 52′ N.	42° 25′W.	43	Aug., 1941– Dec., 1945	1
EUROPE Finland ..	Turku ..	Åbo	60° 27′ N.	22° 10′ E.	20	1938–45	2
	Helsinki ..	Malmi ..	60° 15′ N.	25° 02′ E.	49	1937–46	2
Norway ..	Oslo† ..		59° 55′ N.	10° 43′ E.	295	1931–35	3
Sweden ..	Stockholm ..	Bromma ..	59° 21′ N.	17° 57′ E.	33	1940–45	4
	Göteborg ..	Torslanda ..	57° 42′ N.	11° 47′ E.	16	1940–45	4
Denmark ..	Copenhagen	Kastrop ..	55° 37′ N.	12° 39′ E.	6	1939–45	5
Sweden ..	Malmö ..	Bulltofta ..	55° 36′ N.	13° 03′ E.	20	1940–45	4
Poland ..	Danzig (Gdynia)		54° 31′ N.	18° 33′ E.	46	1931–35	6
Germany ..	Hamburg ..	Fuhlsbuttel ..	53° 38′ N.	10° 00′ E.	59	1931–37	7
	Berlin ..	Tempelhof ..	52° 28′ N.	13° 24′ E.	157	1931–37	7
Holland ..	Amsterdam ..	Schipol ..	52° 18′ N.	4° 48′ E.	−13	1931–33 1935–40	8
Poland ..	Warsaw ..		52° 11′ N.	20° 57′ E.	351	1931–35	6
Belgium ..	Brussels ..	Haren-Evere	50° 53′ N.	4° 25′ E.	180	1938–39	9
Czechoslovakia	Prague ..	Kbely ..	50° 07′ N.	14° 32′ E.	928	1929–39	10
France ..	Paris ..	Le Bourget ..	48° 57′ N.	2° 26′ E.	151	1926–35	11
Austria ..	Vienna ..	Aspern ..	48° 13′ N.	16° 31′ E.	512	1932–37	12
Germany ..	Munich ..	Oberwiesenfeld	48° 11′ N.	11° 33′ E.	1,676	1931–37	7
Austria ..	Vienna ..	Schwechat ..	48° 07′ N.	16° 33′ E.	585	Sept., 1945– Sept., 1946	12
Switzerland ..	Basle ..	Birsfelden ..	47° 33′ N.	7° 38′ E.	853	1936–40	13
	Zürich ..	Dubendorf ..	47° 24′ N.	8° 38′ E.	1,440	1936–40	13
Hungary ..	Budapest ..		47° 21′ N.	18° 59′ E.	350	10 yr.	14
Switzerland ..	Geneva ..	Cointrin ..	46° 14′ N.	6° 05′ E.	1,385	1936–40	13

* The list of Authorities is in Appendix III, p. 86.
† Meteorological station, not airfield.

APPENDIX I—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
0700 Z+3 1330 Z+3	2 2	1 4	2 4	3 1	3 1	1 0	1 2	1 1	3 2	1 3	2 2	2 2	22 24	Bluie West
1100 Z−2 1700 Z−2	8 7	7 5	7 3	4 2	1 0	1 1	1 1	2 0	3 1	7 4	5 5	6 7	52 36	Turku
1100 Z−2 1700 Z−2	7 7	8 6	6 3	4 2	1 0	1 0	1 0	1 0	3 1	4 2	6 4	5 6	47 31	Helsinki
0800 Z−1 1400 Z−1	13 13	13 6	10 3	2 0·6	0·6 0	0 0	0·8 0·2	0 0·2	2 2	5 0·4	7 4	13 12	66 41	Oslo
0800 Z−1 1400 Z−1	7 7	10 6	8 3	4 1	0 0	0 0	0 0	2 0	3 0	7 3	8 4	5 8	54 32	Stockholm
0800 Z−1 1400 Z−1	6 7	8 6	7 4	4 2	1 0	0 0	0 0	1 1	1 0	4 1	4 2	6 6	42 29	Göteborg
0900 Z−1 1500 Z−1	10 9	11 6	9 4	5 2	3 0·3	1 0·6	2 0·4	2 0·1	3 0·7	8 3	6 5	7 5	67 36	Copenhagen
0800 Z−1 1400 Z−1	10 8	10 7	10 7	4 2	2 1	1 0	1 0	3 0	3 1	9 4	10 6	10 9	73 45	Malmö
0800 Z−1 1400 Z−1	7 7	4 4	6 4	4 2	1 0·4	1 1	2 1	1 0·4	3 0·2	5 1	6 3	8 5	48 29	Danzig
0800 Z−1 1400 Z−1	16 14	15 8	17 6	10 2	7 1	3 1	5 1	8 0·4	13 1	15 5	19 13	20 18	148 70	Hamburg
0800 Z−1 1400 Z−1	15 9	12 6	15 4	9 1	3 0·3	1 0·3	2 1	4 1	8 1	14 3	16 10	19 14	118 51	Berlin
0700 Z 1300 Z	9 9	10 7	12 4	6 1	3 1	2 1	2 1	6 1	9 2	10 4	13 8	11 10	93 49	Amsterdam
0800 Z−1 1400 Z−1	19 15	16 12	13 8	6 2	5 3	3 2	3 1	3 2	4 2	7 5	10 6	14 11	103 69	Warsaw
0700 Z 1300 Z	14 13	18 11	18 7	16 2	13 2	3 0·5	9 1	18 2	17 0·5	18 7	17 13	19 16	180 75	Brussels
0800 Z−1 1400 Z−1	17 10	15 7	17 4	11 1	7 0·4	4 0·3	6 0·3	9 0·5	11 0·7	11 2	14 6	14 9	136 41	Prague
0700 Z 1300 Z	19 15	15 8	16 3	10 2	9 1	7 ‡	5 ‡	7 1	12 2	14 4	18 11	16 14	148 61	Paris
0700 Z 1300 Z	15 10	10 5	7 1	3 1	1 1	0 0	0 0	1 0	2 1	4 2	11 6	16 12	70 39	Vienna
0800 Z−1 1400 Z−1	17 9	14 5	15 3	5 1	4 0·7	1 0·3	2 0·4	4 0·2	8 0·4	11 2	19 7	20 12	120 41	Munich
0600 Z 1200 Z	3 4	3 2	6 3	1 0	0 0	0 0	1 0	0 0	1 0	4 0	5 5	8 6	32 20	Vienna
0800 Z−1 1400 Z−1	7 5	7 3	5 2	4 1	6 1	5 1	4 0	10 1	11 1	14 3	6 3	11 6	90 27	Basle
0800 Z−1 1400 Z−1	12 5	12 5	6 1	5 1	3 1	3 1	2 0	7 0	12 1	14 3	14 7	12 9	102 34	Zürich
?	10	5	3	1	1	0·4	0	0·2	2	5	11	13	52§	Budapest
0800 Z−1 1400 Z−1	8 4	8 4	5 2	5 1	1 0	1 0	1 0	2 0	4 1	5 2	10 5	15 6	65 25	Geneva

‡ The average number of days is less than 0·5.
§ Average number of days with "fog", range of visibility unspecified.

APPENDIX I—*continued*

AVERAGE NUMBER OF DAYS WITH VISIBILITY LESS THAN 2½ MILES

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
France ..	Lyons ..	Bron ..	45° 44′ N.	4° 57′ E.	643	1926–35	11
Yugoslavia ..	Belgrade ..		44° 48′ N.	20° 28′ E.	453	1930–34	15
Romania ..	Bucharest ..	Baneasa ..	44° 29′ N.	26° 08′ E.	300	1936–45	16
France ..	Marseilles ..	Istres ..	43° 31′ N.	4° 56′ E.	88	1928–35	11
Bulgaria ..	Sofia ..		42° 42′ N.	23° 24′ E.	1,804	July, 1934–June, 1939	17
Italy	Rome ..	Centocelle ..	41° 53′ N.	12° 34′ E.	164	1928–37	12
Turkey ..	Istanbul ..	Yesilköy ..	40° 58′ N.	28° 50′ E.	59	1940–45	18
	Ankara ..	Elimesut ..	39° 58′ N.	32° 41′ E.	2,686	1940–45	18
Portugal ..	Lisbon ..	Portela ..	38° 46′ N.	9° 09′ W.	328	1938–45	19
Greece ..	Athens ..	Eleusis ..	38° 05′ N.	23° 55′ E.	90	Apr.–Nov., 1945	20
	Athens ..	Hassani ..	37° 54′ N.	23° 48′ E.	26	Nov., 1944–July, 1946	12
Malta ..	Malta ..	Valetta ..	35° 54′ N.	14° 31′ E.	231	1929–44	21
	Malta ..	Luqa ..	35° 51′ N.	14° 28′ E.	77	1943–45	21
ASIA Iraq	Baghdad ..	Baghdad West	33° 20′ N.	44° 24′ E.	112	Apr., 1937–June, 1946	12
Palestine ..	Lydda ..	Lydda ..	32° 00′ N.	34° 54′ E.	131	1939–45	22
Japan	Tokyo ..	Koenji ..	35° 42′ N.	139° 39′ E.	141	1942–44	23
China	Shanghai ..	Zi-Ka-Wei	31° 11′ N.	121° 26′ E.	23	18 yr.	24
India	Delhi ..		28° 35′ N.	77° 12′ E.	714	1933–37	25
Arabia ..	Bahrein ..	Muharraq ..	26° 16′ N.	50° 38′ E.	1	1944–45	12
	Bahrein ..		26° 14′ N.	50° 35′ E.	12	1933–37	25
India	Karachi ..	Manora ..	24° 48′ N.	66° 59′ E.	13	1933–37	25
	Calcutta ..		22° 32′ N.	88° 20′ E.	21	1933–37	25
China	Hongkong ..	Observatory	22° 18′ N.	114° 10′ E.	109	1930–35	23

* The list of Authorities is in Appendix III, p. 86.
† The average number of days is less than 0·5.

APPENDIX I—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
0700 Z 1300 Z	13 6	12 3	8 2	5 †	4 0	2 †	2 0	6 †	7 †	10 1	11 4	13 7	93 23	Lyons
0900 Z−1 1500 Z−1	11 10	5 2	4 2	0·8 0·2	0·2 0	0 0	0 0	0 0	0·2 0	2 2	3 1	7 6	33 23	Belgrade
0800 Z−2 1400 Z−2	21 14	18 9	5 2	4 0	1 0	1 0	1 0	0 0	2 0	7 2	18 6	17 11	95 44	Bucharest
0700 Z 1300 Z	1 1	1 †	2 †	1 †	1 0	1 †	† †	2 †	1 †	2 1	2 1	3 1	17 4	Marseilles
0900 Z−2 1500 Z−2	9 6	3 2	3 2	0·6 0·3	0·4 0·3	0·6 0·9	0 0·8	0·2 0·4	0 0	2 0·7	6 1	5 4	30 18	Sofia
0700 Z−1 1300 Z−1	3 1	4 3	5 2	6 2	8 1	7 0	5 0	5 1	5 1	6 1	5 1	6 3	65 16	Rome
0800 Z−2 1400 Z−2	4 2	3 1	1 0	1 0	0 0	0 0	0 0	0 0	0 0	1 0	1 0	1 1	12 4	Istanbul
0800 Z−2 1400 Z−2	3 2	4 0	1 1	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 1	4 1	13 5	Ankara
0930 Z 1230 Z	4 2	2 1	2 0	1 1	0 0	0 0	0 0	0 0	1 0	1 0	5 2	6 4	22 10	Lisbon
0800 Z−2 1400 Z−2	– –	– –	– –	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	– –	– –	Athens
0800 Z−2 1400 Z−2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 1	1 0	1 1	Athens
0800 Z−1 1400 Z−1	0·1 0	0·1 0·1	0 0	0·2 0	0 0·1	0·1 0	0 0	0 0	0 0·1	0·2 0	0·1 0	0·2 0·1	1 0·4	Malta
0800 Z−1 1400 Z−1	0 0·3	0 0	0·3 0·3	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0·3 0	0·3 0	0·9 0·6	Malta
0500 } 0600 } Z−3	1	0·8	0·4	0·7	0·7	0·1	0·3	0·3	0	0·2	0·9	2	7	Baghdad
1500 } 1600 } Z−3	2	1	1	0·9	0·8	0·3	1	1	0·6	0·7	0·9	0·8	11	
0800 Z−2 1400 Z−2	0·8 1	0·5 0·7	1 0·8	0·2 0·3	0·1 0·3	0 0	0 0	0 0	0 0	0·2 0·2	0·2 0	0·2 0·2	3 3	Lydda
0600 Z−9 1400 Z−9	15 6	7 5	16 8	17 4	24 7	23 4	26 3	7‡ 0‡	13‡ 1‡	19 5	16 6	13‡ 3‡	196 52	Tokyo
All hours	2	4	4	3	5	3	1	2	3	5	5	4	41§	Shanghai
Morning Afternoon	3 0	2 0·2	0·8 0·2	0·2 0·2	1 0·6	3 3	0 0·2	0·8 0	0·6 0·2	1 0·2	1 0·4	3 0	16 5	Delhi
1000 Z−4 1600 Z−4	2 1	4 1	3 1	0 0	5 5	5 0	11 3	5 1	3 0	1 0	0 1	1 0	40 13	Bahrein
Morning Afternoon	3 0·6	5 2	3 0·8	1 1	2 1	6 3	10 5	5 2	1 0·8	2 0·2	2 0	2 0	42 16	Bahrein
Morning Afternoon	1 1	3 0·2	1 0·6	1 0	1 0·2	6 2	8 4	2 1	0·6 0·2	1 0·4	2 0·4	1 0	28 10	Karachi
Morning Afternoon	30 24	26 6	21 5	8 5	7 6	8 5	10 9	9 6	9 10	22 17	29 25	30 30	209 148	Calcutta
0600 Z−8 1200 Z−8	1 2	2 2	3 4	4 4	2 1	2 2	2 1	2 1	3 2	0 0	1 1	2 2	24 22	Hongkong

‡ Records from Tachikawa 35° 41′ N. 139° 24′ E. Ht. 295 ft.
§ Average number of days per month with visibility less than 1,100 yd.

APPENDIX I—*continued*

AVERAGE NUMBER OF DAYS WITH VISIBILITY LESS THAN $2\frac{1}{2}$ MILES

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
Arabia ..	Masirah ..	Ras Hedf ..	20° 39′ N.	58° 54′ E.	52	1943–45	12
Burma ..	Rangoon ..	Mingaladon	16° 46′ N.	96° 11′ E.	16	May, 1945–June, 1946	23
Ceylon ..	Colombo ..	Negombo ..	7° 10′ N.	79° 53′ E.	26	Several years	23
	Colombo ..	Observatory	6° 54′ N.	79° 52′ E.	23	Feb., 1943–Oct., 1945	23
Malaya ..	Singapore ..	Kallang ..	1° 18′ N.	103° 53′ E.	7	1938–41	23
AFRICA Algeria ..	Algiers ..	Maison Blanche	36° 43′ N.	3° 14′ E.	73	1935–38 1945	11
Egypt	Cairo ..	Almaza ..	30° 07′ N.	31° 21′ E.	246	1941–45	12
	Cairo ..	Heliopolis ..	30° 05′ N.	31° 22′ E.	167	1923–45	12
Algeria ..	Adrar ..		27° 52′ N.	0° 17′ W.	938	1933–38	11
Sudan ..	Khartoum	Stack Laboratory	15° 37′ N.	32° 32′ E.	1,243	1937–45	12
	Khartoum ..	Airfield ..	15° 36′ N.	32° 33′ E.	1,250	July, 1944–June, 1946	12
Gambia ..	Bathurst ..		13° 27′ N.	16° 34′ W.	10	1943–45 1943–47	26
	Yundum ..		13° 21′ N.	16° 40′ W.	92	Jan., 1945–July, 1947	26
Nigeria ..	Kano ..	Kano North	12° 02′ N.	8° 32′ E.	1,535	Apr., 1938–May, 1947	26
	Lagos ..	Ikeja ..	6° 35′ N.	3° 20′ E.	121	Jan., 1944–May, 1947	26
	Lagos ..	Apapa ..	6° 27′ N.	3° 24′ E.	12	1940–44	26
Gold Coast ..	Accra ..	Accra ..	5° 36′ N.	0° 10′ W.	213		26
Kenya	Nairobi ..	Eastleigh ..	1° 17′ S.	36° 50′ E.	5,371	1942–45	27
	Nairobi ..	Town ..	1° 14′ S.	36° 44′ E.	5,900	1936–45	27

* The list of Authorities is in Appendix III, p. 86.
† Estimated values.

APPENDIX I—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
1000 Z−4	0	1	2	0	0	0	2	0	0	0	0	0	5	Masirah
1600 Z−4	1	1	1	0	0	2	2	0	0	0	0	0	7	
0600 Z−6½	5	10	15	1	1	2	2	4	1	1	2	1	45	Rangoon
1200 Z−6½	0	0	0	0	1	2	1	1	0	0	0	0	5	
0600 Z−5½	0	0	0	0	0	0	0	0	0	0	0	0	0†	Colombo
1200 Z−5½	0	0	0	0	0	0	0	0	0	0	0	0	0†	
1030 Z−5½	0	1	1	0	2	1	0	0	1	2	1	2	11	Colombo
1630 Z−5½	0	0	0	0	0	0	0	0	0	0	0	0	0	
0730 Z−7½	4	7	9	8	8	7	8	9	9	8	6	5	88	Singapore
1330 Z−7½	1	1	0	0	0	1	1	1	1	1	1	0	8	
0700 Z	2	2	4	5	2	1	2	‡	1	2	1	‡	22	Algiers
1300 Z	‡	‡	0	‡	1	0	0	0	0	‡	0	0	1	
0800 Z−2	3	3	2	2	1	0·5	1	1	1	1	3	5	24	Cairo
1400 Z−2	1	1	1	1	0·5	0	0	0	0	0	1	1	7	
0800 Z−2	2	3	2	2	1	0·5	1	1	2	3	4	5	26	Cairo
1400 Z−2	1	0·5	1	0·5	0	0	0	0	0	0	0	0	3	
0700 Z	‡	1	1	1	‡	1	1	1	1	0	1	‡	8	Adrar
1300 Z	‡	2	2	1	1	1	‡	1	‡	1	‡	‡	9	
0800 Z−2	0·4	2	2	2	3	2	1	0·4	0·8	0	0·1	0·1	14	Khartoum
1400 Z−2	3	2	4	2	2	1	0·8	0·8	0	0·2	0	0·2	16	
0800 Z−2	0	0·5	1	2	2	1	2	1	0	0	0	0	10	Khartoum
1400 Z−2	0	0·5	1	1	1	1	1	0	0	0	0	0·5	6	
0500 Z+1	1	2	2	0	1	0	0·3	0·3	0·6	1	0	0·3	9	Bathurst
1100, 1200, 1400 Z+1	1	3	3	2	2	0	0·3	0	0·3	0	1	0·7	13	
0200,0500 Z+1	0·7	1	4	4	1	0	0·3	1	0	0	1	5	18	Yundum
1100, 1400 Z+1	0	0·7	3	3	1	0·3	0	0·5	0·5	0	1	0·5	11	
0700, 0800 Z−1	4	6	5	1	0·1	0	0·1	0·4	0	1	2	3	23	Kano
1300, 1400, 1500 Z−1	4	6	5	3	0·2	0	0	0	0·3	1	2	3	25	
0400, 0700, 0800 Z−1	21	9	5	1	3	3	7	10	3	5	6	17	90	Lagos
1300, 1600 Z−1	2	3	0·3	0	0·5	0·3	0·5	0·3	0·5	0	0	1	8	
0700, 0800 Z−1	8	7	1	0·6	1	1	0·6	2	1	2	2	11	37	Lagos
1300 Z−1	2	1	0	0	0·4	0·6	0	0·4	0	0·4	0	0	5	
0700 Z	5	2	0·8	0·4	0·4	0·6	1	2	0·7	0·7	0	3	17	Accra
1300 Z	3	0·2	0·2	0	0	0·8	0·2	0·6	0	0	0	0·5	5	
0830 Z−2½	0	0	1	1	0	1	3	1	1	0	1	0	9	Nairobi
1430 Z−2½	0	0	0	0	0	0	0	0	0	0	0	0	0	
0830 Z−2½	0	0	2	2	2	1	1	1	1	0	1	0	11	Nairobi
1430 Z−2½	0	0	1	0	1	0	0	0	0	0	0	0	2	

‡ The average number of days is less than 0·5.

APPENDIX I—*continued*

AVERAGE NUMBER OF DAYS WITH VISIBILITY LESS THAN $2\frac{1}{2}$ MILES

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
Belgian Congo	Leopoldville	N'Dolo ..	4° 20′ S.	15° 19′ E.	1,007	1940–41 1943–45 1941–45	9
Rhodesia ..	Salisbury ..	Belvedere ..	17° 50′ S.	31° 01′ E.	4,780	July, 1936– June, 1946	28
South-west Africa	Walvis Bay ..	Windhoek ..	22° 34′ S.	17° 05′ E.	5,610	Mar., 1943– Apr., 1946	29
Transvaal ..	Johannesburg	Germiston ..	26° 14′ S.	28° 08′ E.	5,448	1936–45	29
Natal ..	Durban ..	—	29° 51′ S.	31° 03′ E.	42	1936–46 1940–46	29
Cape of Good Hope	Capetown ..	Wingfield ..	33° 55′ S.	18° 32′ E.	56	1933–43	29
	Port Elizabeth	—	33° 59′ S.	25° 37′ E.	205	1942–45	29
NORTH AMERICA Labrador ..	Goose Bay ..	Goose ..	53° 20′ N.	60° 24′ W.	150	1942–45	30
Newfoundland	Gander ..	—	48° 57′ N.	54° 34′ W.	493	1941–45	30
Quebec ..	Montreal ..	Dorval ..	45° 27′ N.	73° 46′ W.	104	1941–45	30
Massachusetts	Boston ..	Municipal ..	42° 22′ N.	71° 02′ W.	29	1936–45	1
Illinois ..	Chicago ..	Municipal ..	41° 47′ N.	87° 44′ W.	623	1936–41	1
New York ..	New York	La Guardia	40° 46′ N.	73° 53′ W.	12	Jan., 1942– Apr., 1946	1
Bermuda ..	Bermuda ..	Kindley Field	32° 22′ N.	64° 40′ W.	16	Dec., 1941– July, 1946	31
Louisiana ..	New Orleans	Municipal ..	30° 02′ N.	90° 02′ W.	30	Mar., 1932– Feb., 1946	1
Florida ..	Miami ..	36th Street ..	25° 48′ N.	80° 16′ W.	8	Jan., 1942– May, 1946	1
SOUTH AMERICA Brazil	Natal ..	Pitimbi ..	5° 53′ S.	35° 14′ W.	161	1941–45	32
	Rio de Janeiro	Santos Damont	22° 54′ S.	43° 10′ W.	8	1941–45	32
Chile	Santiago ..	—	33° 27′ S.	70° 42′ W.	1,706	1939–43	33
Argentine ..	Buenos Aires	Morón ..	34° 40′ S.	58° 38′ W.	69	1941–45	34
Uruguay ..	Montvideo ..	Central Observatory	34° 55′ S.	56° 13′ W.	79	23 yr.	35

* The list of Authorities is in Appendix III, p. 86.
† Cannot be accepted as means owing to very short period, also because last years were abnormally dry.

APPENDIX I—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
0700 Z−1 1400 Z−1	12 1	12 1	9 1	9 1	15 3	19 6	23 6	14 2	10 3	9 1	4 2	9 3	145 30	Leopoldville
0800 Z−2 1400 Z−2	1 1	3 1	3 0	3 0	2 0	2 0	3 0	4 1	6 2	3 1	0 0	2 1	32 7	Salisbury
0830 Z−2 1500 Z−2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0·3	0 0	0 0	0 0	0 0·6	0† 0·9†	Walvis Bay
0830 Z−2 1500 Z−2	0·7 0·3	2 0·6	3 0·2	4 0·4	5 0·3	7 0·7	6 0·1	5 0·6	4 1	2 1	0·8 0·3	2 0·5	41 6	Johannesburg
0830 Z−2 1500 Z−2	2 0·4	2 0·4	1 0·4	1 0·4	3 0·4	3 0·1	3 0·2	3 1	1 1	2 1	3 1	2 1	26 7	Durban
0830 Z−2 1500 Z−2	1 0·2	2 0·2	4 0·1	5 0·3	6 0·8	6 1	3 0·6	3 0·6	3 0·8	2 0·4	0·9 0·1	0·7 0	37 5	Capetown
0830 Z−2 1500 Z−2	2 0·7	5 0·7	3 0·7	2 0·3	2 1	2 0·3	1 0·3	0·7 1	2 1	2 1	3 1	3 0·5	28 9	Port Elizabeth
0730 Z+3½ 1330 Z−3½	2 2	5 5	4 4	3 2	3 2	0 1	1 0	2 1	1 1	2 2	2 3	5 5	30 28	Goose Bay
0730 Z+3½ 1330 Z+3½	7 7	8 8	7 6	7 6	7 3	6 2	4 2	2 2	6 3	4 3	6 5	6 7	70 54	Gander
0730 Z+5 1330 Z+5	8 6	7 4	7 4	3 3	2 1	2 1	4 1	4 1	5 1	6 2	7 3	10 6	65 33	Montreal
0730 Z+5 1330 Z+5	4 3	5 3	5 3	4 2	6 2	4 1	6 1	5 1	5 1	4 2	3 2	4 3	55 24	Boston
0730 Z+6 1330 Z+6	9 9	7 6	11 5	9 4	9 3	10 2	8 1	12 1	11 7	10 2	5 2	8 8	109 50	Chicago
0730 Z+5 1330 Z+5	4 5	4 4	6 4	6 2	6 2	7 2	5 1	6 1	6 3	3 3	3 3	3 5	59 35	New York
All hours	6	5	4	3	4	3	2	3	3	4	4	5	46‡	Bermuda
0730 Z+6 1330 Z+6	5 2	4 2	6 0·4	5 1	4 0·2	1 0·1	1 0·1	2 1	2 0·3	5 0·3	6 1	7 2	48 10	New Orleans
0730 Z+5 1330 Z+5	2 0·2	3 0·2	3 0·2	2 0	3 0·4	1 1	1 0·3	0·3 0	0·3 0	1 1	1 0	2 0	20 3	Miami
0600 Z+3 1200 Z+3	0 0	1 1	1 0	0 0	1 0	2 1	2 1	1 0	0 0	0 0	0 0	0 0	8 3	Natal
0400 Z+3 1000 Z+3	9 2	5 1	12 1	13 5	13 3	15 4	14 2	14 5	13 7	13 8	8 3	8 4	137 45	Rio de Janeiro
0900 Z+5 1400 Z+5	18 0	17 →	19 ←	16 2	15 →	14 ←	14 7	15 →	14 ←	15 0·5	12 →	13 ←	182 9	Santiago
0430 Z+4 1030 Z+4	2 1	3 1	7 1	9 1	10 2	13 3	9 4	9 5	6 2	3 0	1 0	1 0	73 20	Buenos Aires
Unspecified	0	0	2	3	6	9	9	6	5	3	1	1	45§	Montevideo

‡ Average for months, visibility below 3 miles.
§ Average number of days with fog, range of visibility not stated.

APPENDIX I—*continued*

AVERAGE NUMBER OF DAYS WITH VISIBILITY LESS THAN $2\frac{1}{2}$ MILES

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
AUSTRALASIA							
Western Australia	Darwin ..	R.A.A.F. ..	12° 26′ S.	130° 53′ E.	52	1941–45	36
Queensland ..	Cloncurry ..	—	20° 41′ S.	140° 30′ E.	618	1940–45	36
	Brisbane ..	Archerfield ..	27° 35′ S.	153° 01′ E.	85	1940–45	36
New South Wales	Sydney ..	Mascot ..	33° 57′ S.	151° 10′ E.	22	1940–45	36
New Zealand ..	Auckland ..	Whenuapai ..	36° 47′ S.	174° 38′ E.	85	Feb., 1942– June, 1946	37
	Wellington ..	Rongotai ..	41° 19′ S.	174° 48′ E.	10	Oct., 1943– June, 1946 Jan., 1939– June, 1946	37

* The list of Authorities is in Appendix III, p. 86.

APPENDIX I—*continued*

AT THE TIME (LOCAL) SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
1400 Z − 8	3	3	2	2	0	1	0	0	0	2	2	2	17	Darwin
2000 Z − 8	2	4	4	1	0	0	0	1	3	4	1	1	21	
1600 Z − 10	1	2	1	1	0	0	0	0	0	1	2	2	10	Cloncurry
2200 Z − 10	2	3	2	2	1	0	0	0	1	2	1	2	16	
1600 Z − 10	5	6	6	6	7	4	4	11	13	11	9	5	87	Brisbane
2200 Z − 10	2	2	2	1	1	1	2	1	3	4	5	2	26	
1600 Z − 10	13	13	12	11	9	6	4	7	13	12	12	13	125	Sydney
2200 Z − 10	4	5	5	4	4	5	4	2	4	6	5	6	54	
2100 Z − 12	0	1	2	2	3	4	4	4	1	1	1	0	23	Auckland
2400 Z − 12	1	0	1	1	1	1	1	1	1	2	1	0	11	
1800 Z − 12	1	1	2	0	1	0	0	3	1	0	1	1	11	Wellington
2400 Z − 12	1	1	2	1	2	1	1	2	1	2	1	1	16	

APPENDIX II

AVERAGE NUMBER OF DAYS WITH CLOUD BASE 1,000 FT. OR LESS

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
Greenland ..	Bluie West ..	Narsarssuak	61° 52′ N.	42° 54′ W.	43	Aug., 1941–Dec., 1945	1
EUROPE							
Finland ..	Turku ..	Åbo ..	60° 27′ N.	22° 10′ E.	20	1938–45	2
	Helsinki ..	Malmi ..	60° 15′ N.	25° 02′ E.	49	1937–46	2
Norway ..	Oslo† ..	—	59° 55′ N.	10° 43′ E.	295	1931–35	3
Sweden ..	Stockholm ..	Bromma ..	59° 21′ N.	17° 57′ E.	33	1940–45	4
	Göteborg ..	Torslanda ..	57° 42′ N.	11° 47′ E.	16	1940–45	4
Denmark ..	Copenhagen	Kastrop ..	55° 37′ N.	12° 39′ E.	6	1939–45	5
Sweden ..	Malmö ..	Bulltofta ..	55° 36′ N.	13° 03′ E.	20	1940–45	4
Germany ..	Hamburg ..	City ..	53° 38′ N.	10° 00′ E.	59	1931–37	7
	Hamburg ..	Fuhlsbuttel ..	53° 38′ N.	10° 00′ E.	59	1931–37	7
	Berlin ..	Tempelhof ..	52° 28′ N.	13° 24′ E.	157	1931–37	7
Holland ..	Amsterdam ..	Schipol ..	52° 18′ N.	4° 48′ E.	−13	1931–33 1935–40	8
Poland ..	Warsaw ..	—	52° 11′ N.	20° 57′ E.	351	1931–35	6
Belgium ..	Brussels ..	Haren ..	50° 53′ N.	4° 25′ E.	180	1938–39	9
Czechoslovakia	Prague ..	Kbely ..	50° 07′ N.	14° 32′ E.	928	1929–38	10
France ..	Paris ..	Le Bourget ..	48° 57′ N.	2° 26′ E.	151	1926–35	11
Austria ..	Vienna ..	Aspern ..	48° 13′ N.	16° 31′ E.	512	1932–37	12
Germany ..	Munich ..	Oberwiesenfeld	48° 11′ N.	11° 33′ E.	1,676	1931–37	7
Austria ..	Vienna ..	Schwechat ..	48° 07′ N.	16° 33′ E.	585	Sept., 1945–Sept., 1946	12
Switzerland ..	Basle ..	Birsfelden ..	47° 33′ N.	7° 38′ E.	853	1936–40	13
	Zürich ..	Dubendorf ..	47° 24′ N.	8° 38′ E.	1,440	1936–40	13
	Geneva ..	Cointrin ..	46° 14′ N.	6° 05′ E.	1,385	1936–40	13

* The list of Authorities is in Appendix III, p. 86.
† Meteorological station, not airfield.

APPENDIX II—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
0730 Z+3	1	1	1	1	5	5	5	5	5	2	2	2	35	Bluie West
1330 Z+3	1	3	3	2	2	1	3	4	5	3	2	3	32	
1100 Z−2	14	12	9	8	4	5	4	5	8	13	14	13	109	Turku
1700 Z−2	13	10	7	4	2	3	2	2	4	9	13	13	82	
1100 Z−2	15	14	10	8	4	5	4	6	9	12	16	17	120	Helsinki
1700 Z−2	14	12	6	5	4	3	3	2	5	9	15	17	95	
0800 Z−1	18	12	10	7	8	2	10	7	9	9	13	13	118	Oslo
1400 Z−1	18	11	9	7	6	2	10	6	8	10	12	12	111	
0800 Z−1	9	9	8	6	3	2	4	6	7	11	12	12	89	Stockholm
1400 Z−1	8	9	6	3	2	1	2	2	4	7	14	12	70	
0800 Z−1	7	9	9	6	3	3	4	4	4	8	9	11	77	Göteborg
1400 Z−1	8	8	7	4	2	1	2	2	3	5	7	13	62	
0900 Z−1	10	13	9	7	3	4	5	6	5	7	9	10	88	Copenhagen
1500 Z−1	12	10	8	4	0·9	1	0·9	2	2	7	8	10	66	
0800 Z−1	11	12	10	6	3	4	5	7	7	9	11	11	96	Malmö
1400 Z−1	11	10	8	4	2	1	1	2	3	7	8	13	70	
0800 Z−1	8	10	5	6	4	2	5	4	4	8	9	10	75	Hamburg
1400 Z−1	6	7	4	4	2	1	4	2	1	5	7	6	49	
0800 Z−1	11	12	7	7	6	4	6	5	5	9	13	15	100	Hamburg
1400 Z−1	10	12	4	4	3	0·4	2	1	2	6	9	12	65	
0800 Z−1	8	10	7	7	4	4	4	5	5	8	14	9	85	Berlin
1400 Z−1	8	7	5	2	1	1	1	1	1	3	9	11	50	
0700 Z	10	7	7	7	5	4	5	4	5	6	9	9	78	Amsterdam
1300 Z	10	9	6	4	2	2	3	2	3	5	8	10	64	
0800 Z−1	20	18	11	8	7	6	6	7	6	10	15	19	133	Warsaw
1400 Z−1	17	15	12	7	6	5	4	4	6	10	15	16	117	
0700 Z	12	11	9	9	6	5	5	8	11	11	11	14	112	Brussels
1300 Z	12	5	3	5	3	3	1	4	0·5	9	14	10	69	
0800 Z−1	6	4	2	2	1	0·8	0·7	0·8	1	2	5	6	31	Prague
1400 Z−1	5	3	1	0·5	0·5	0·4	0·7	0·2	0·1	1	3	5	20	
0700 Z	11	7	6	4	4	3	4	4	5	6	11	11	76	Paris
1300 Z	7	6	2	1	1	1	‡	1	1	2	7	9	38	
0700 Z	10	4	3	2	1	0	0	0	0	3	8	13	44	Vienna
1300 Z	7	4	1	0	0	0	0	0	0	2	6	12	32	
0800 Z−1	9	5	5	4	4	3	2	4	4	7	12	12	71	Munich
1400 Z−1	8	4	4	2	2	1	1	1	1	4	9	10	47	
0600 Z	9	4	4	0	0	0	1	0	0	3	8	4	33	Vienna
1200 Z	3	2	4	0	0	2	0	0	0	0	9	5	25	
0800 Z−1	3	3	4	3	5	2	2	6	11	11	5	5	60	Basle
1400 Z−1	1	4	1	1	1	0	0	1	1	2	1	2	15	
0800 Z−1	8	8	3	5	5	6	5	7	8	14	11	11	91	Zurich
1400 Z−1	4	2	1	1	2	0	1	0	1	4	5	7	28	
0800 Z−1	5	6	2	1	1	0	1	0	1	5	7	7	36	Geneva
1400 Z−1	3	4	2	1	0	0	0	0	0	1	3	4	18	

‡ The average number of days is less than 0·5.

APPENDIX II—*continued*

AVERAGE NUMBER OF DAYS WITH CLOUD BASE 1,000 FT. OR LESS

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
France ..	Lyons ..	Bron ..	45° 44′ N.	4° 57′ E.	643	1926–35	11
Yugoslavia ..	Belgrade ..	—	44° 48′ N.	20° 28′ E.	453	1930–34	15
Romania ..	Bucharest ..	Baneasa ..	44° 29′ N.	26° 08′ E.	300	1936–45	16
France ..	Marseilles ..	Istres ..	43° 31′ N.	4° 56′ E.	88	1928–35	11
Bulgaria ..	Sofia ..	—	42° 42′ N.	23° 24′ E.	1,804	July, 1934–June, 1939	17
Italy	Rome ..	Centocelle ..	41° 53′ N.	12° 34′ E.	164	1931–37	12
Turkey ..	Istanbul ..	Yesilkoy ..	40° 58′ N.	28° 50′ E.	59	1940–45	18
	Ankara ..	Elimesut ..	39° 58′ N.	32° 41′ E.	2,686	1940–45	18
Portugal ..	Lisbon ..	Portela ..	38° 46′ N.	9° 09′ W.	328	1938–45	19
Greece ..	Athens ..	Eleusis ..	38° 05′ N.	23° 55′ E.	90	Apr.–Nov., 1945	20
	Athens ..	Hassani ..	37° 54′ N.	23° 48′ E.	26	Nov., 1944–July, 1946	12
Malta	Malta ..	Valetta ..	35° 54′ N.	14° 31′ E.	231	1929–44	21
	Malta ..	Luqa ..	35° 51′ N.	14° 28′ E.	77	1943–45	21
ASIA Iraq	Baghdad ..	Baghdad West	33° 20′ N.	44° 24′ E.	112	Apr., 1937–June, 1946	12
Palestine ..	Lydda ..	Lydda ..	32° 00′ N.	34° 54′ E.	131	1939–45	22
Japan	Tokyo ..	Koenji ..	35° 42′ N.	139° 39′ E.	141	1942–44	23
India	Delhi ..	—	28° 35′ N.	77° 12′ E.	714	1937–42	25
Arabia ..	Bahrein ..	Muharraq ..	26° 16′ N.	50° 38′ E.	1	1944–45	12
	Bahrein ..	—	26° 14′ N.	50° 35′ E.	12	1937–42	25
India	Karachi ..	Manora ..	24° 48′ N.	66° 59′ E.	13	1937–42	25
	Calcutta ..	—	22° 32′ N.	88° 20′ E.	21	1937–42	25
China	Hongkong ..	Observatory	22° 18′ N.	114° 10′ E.		1884–1933	23
Arabia ..	Masirah ..	Ras Hedf ..	20° 39′ N.	58° 54′ E.	52	1943–45	12

* The list of Authorities is in Appendix III, p. 86.
† The average number of days less than 0·5.

APPENDIX II—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
0700 Z 1300 Z	7 4	5 2	3 1	1 †	2 †	1 †	2 †	2 1	3 1	5 1	7 4	9 6	47 20	Lyons
0900 Z−1 1500 Z−1	4 4	2 0·2	0·6 0·2	0·4 0	0·2 0	0·2 0·5	0 0	0·2 0	0 0·2	0·8 0·5	1 0	2 3	11 9	Belgrade
0800 Z−2 1400 Z−2	11 9	9 7	5 2	4 2	3 1	1 0	0 0	1 0	2 1	6 2	11 7	13 10	66 41	Bucharest
0700 Z 1300 Z	† †	† †	1 †	† †	1 0	† 0	† 0	1 †	1 †	2 1	1 1	1 †	8 2	Marseilles
0900 Z−2 1500 Z−2	5 3	2 0·9	2 2	0·9 0	0·4 0·6	0·4 0·3	0·3 0	0 0·4	0·4 0·4	3 0·7	3 1	3 0·6	20 10	Sofia
0700 Z−1 1300 Z−1	2 0·2	1 0·2	2 0	4 0	3 0	2 0·1	2 0	1 0·2	1 0	3 0	2 0·3	3 0·3	26 1	Rome
0800 Z−2 1400 Z−2	5 5	6 3	7 4	5 2	4 1	2 0	2 0	1 0	2 2	3 2	4 2	5 4	46 25	Istanbul
0800 Z−2 1400 Z−2	3 2	2 2	3 1	1 1	1 0	0 0	0 0	0 0	0 0	1 1	1 1	3 2	15 10	Ankara
0930 Z 1230 Z	9 9	6 4	4 4	5 4	3 2	2 2	1 1	0 0	2 2	4 3	4 5	7 7	47 43	Lisbon
0800 Z−2 1400 Z−2	– –	– –	– –	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	– –	– –	Athens
0800 Z−2 1400 Z−2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 1	1 2	2 3	Athens
0800 Z−1 1400 Z−1	0·3 0·3	0·3 0·7	1 0·7	2 0·7	1 0·3	1 0·3	2 0·4	0·2 0·2	0·3 0·1	0·3 0·1	0·7 0·2	0·3 0·3	9 4	Malta
0800 Z−1 1400 Z−1	0·3 0·3	1 0·3	2 0·3	2 0·7	1 0·7	0·7 0	2 0·3	0·7 0	1 0	0·3 0	1 0·3	2 1	14 4	Malta
0500, 0600 Z−3	1	0·7	0·1	0·2	0	0·1	0	0	0	0	0·2	0·4	3	Baghdad
1500, 1600 Z−3	2	1	0·4	0·5	0·3	0	0·3	0·3	0	0·1	0·6	0·9	6	
0800 Z−2 1400 Z−2	1 0·7	0·2 0	0·2 0·2	1 0	0·9 0	0·3 0·2	0·2 0	0 0	0 0	0·3 0	0·5 0·2	0·2 0	5 1	Lydda
0600 Z−9 1400 Z−9	0 0	1 1	4 4	3 1	6 4	9 0·5	12 1	5‡ 0‡	10‡ 1‡	9 3	3 1	5‡ 0‡	67 17	Tokyo
Unspecified	0·9	0·3	0	0	0·3	0	0·3	0·3	0·3	0	0	0	2	Delhi
1000 Z−4 1600 Z−4	1 1	0 0	1 0	0 0	0 0	0 0	0 0	1 0	2 0	1 0	0 0	1 0	7 1	Bahrein
Unspecified	0	0	0	0	0	0	0	0	0	0	0·3	0	0·3	Bahrein
Unspecified	0	0	0	0	0	0	0	0	0	0	0	0	0	Karachi
Unspecified	0	0	0	0	0	0	2	0·6	0·3	0·3	0·3	0	3	Calcutta
Unspecified	3	5	7	7	4	3	1	2	1	1	1	2	37	Hongkong
1000 Z−4 1600 Z−4	0 0	0 0	0 0	0 0	0 0	2 0	5 1	8 0	5 1	1 0	0 0	0 0	21 2	Masirah

‡ Records from Tachikawa 35° 41′ N. 139° 24′ E., 295 ft.

APPENDIX II—*continued*

AVERAGE NUMBER OF DAYS WITH CLOUD BASE 1,000 FT. OR LESS

Country	Place	Airfield or Observatory	Lat.	Long.	Height	Period	Authority*
					ft.		
Burma ..	Rangoon ..	Mingaladon	16° 46′ N.	96° 11′E.	16	May, 1945–June, 1946	23
Ceylon ..	Colombo ..	Negombo ..	7° 10′ N.	79° 53′ E.	26	Several years	23
	Colombo ..	Observatory	6° 54′ N.	79° 52′ E.	23	Feb., 1943–Oct., 1945	23
Malaya ..	Singapore ..	Kallang ..	1° 18′ N.	103° 53′ E.	7	1938–41	23
AFRICA Algeria ..	Algiers ..	Maison Blanche	36° 43′ N.	3° 14′ E.	73	1935–38 1945	11
Egypt	Cairo ..	Almaza ..	30° 07′ N.	31° 21′ E.	246	1941–45	12
	Cairo ..	Heliopolis ..	30° 05′ N.	31° 22′ E.	167	1923–45	12
Algeria ..	Adrar† ..	—	27° 52′ N.	0° 17′ W.	938	1933–38	11
Sudan ..	Khartoum ..	Stack Laboratory	15° 37′ N.	32° 32′ E.	1,243	1937–45 1937–41	12
	Khartoum ..	Airfield ..	15° 36′ N.	32° 33′ E.	1,250	July, 1944–June, 1946	12
Gambia ..	Bathurst ..	—	13° 27′ N.	16° 34′ W.	10	1943–45	26
	Yundum ..	—	13° 21′ N.	16° 40′ W.	92	1945	26
Nigeria ..	Kano ..	Kano North	12° 02′ N.	8° 32′ E.	1,535	Apr., 1938–May, 1947	26
	Lagos ..	Ikeja ..	6° 35′ N.	3° 20′ E.	121	1944–May, 1947	26
	Lagos ..	Apapa ..	6° 27′ N.	3° 24′ E.	12	1940–44	26
Gold Coast ..	Accra ..	Accra ..	5° 36′ N.	0° 10′ W.	213	Jan., 1938–Aug., 1942	26
Kenya.. ..	Nairobi ..	Eastleigh ..	1° 17′ S.	36° 50′ E.	5,371	1942–45	27
	Nairobi ..	Town ..	—	—	—	1936–45	27
Belgian Congo	Leopoldville	N'Dolo ..	4° 20′ S.	15° 19′ E.	1,007	1940–45	8

* The list of Authorities is in Appendix III, p. 86.
† Sky sometimes invisible by sandstorm.

APPENDIX II—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
0600 Z − 6½ 1200 Z − 6½	0 0	0 0	0 0	3 0	0·5 3	3 5	5 6	10 6	10 7	2 2	2 0	3 0	38 29	Rangoon
0600 Z − 5½ 1200 Z − 5½	2 0	0 0	1 0	1 0	1 1	0 0	0 0	0 0	0 0	1 1	1 2	1 2	8§ 6§	Colombo
1030 Z − 5½ 1630 Z − 5½	0 0	0 0	1 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	1 0	Colombo
0730 Z − 7½ 1330 Z − 7½	1 1	1 1	1 1	1 1	1 2	1 1	2 1	1 2	1 1	1 1	2 1	1 2	14 15	Singapore
1700 Z 1300 Z	1 ‡	1 ‡	1 0	1 ‡	‡ 1	1 0	1 0	1 0	‡ 0	0 ‡	0 0	0 0	7 1	Algiers
0800 Z − 2 1400 Z − 2	0·5 0	1 0	0·5 0	1 0	0 0	0·5 0	1 0	1 0	2 0	1 0	1 0	1 0	11 0	Cairo
0800 Z − 2 1400 Z − 2	1 0	0·5 0	1 0	1 0	0·5 0	1 0	3 0	2 0	3 0	3 0	3 0	1 0	20 0	Cairo
0700 Z 1300 Z	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	Adrar
0800 Z − 2 1400 Z − 2	0 0	0 0	0 0	0 0	0·2 0	0·2 0	0 0	0 0	0 0	0 0	0 0	0 0	0·4 0	Khartoum
0800 Z − 2 1400 Z − 2	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	Khartoum
0500 Z + 1	0	0	0	2	3	0·6	0·3	0·6	1	0	0	0·3	8	Bathurst
1100, 1200, 1400 Z + 1	0·3	0	0	0	0·6	1	0	0·6	0·3	0	0	0	3	
0200, 0500 Z + 1	0	0	0	1	1	0	2	6	2	0	0	0	12	Yundum
1100, 1400 Z + 1	0	0	0	1	1	1	0	2	4	0	0	0	9	
0700, 0800 Z − 1	0	0	0	0·1	0·4	0	0·1	0·9	1	0	0	0	3	Kano
1300, 1400, 1500 Z − 1	0	0	0	0	0·2	0	0	0·4	0	0·1	0	0	0·7	
0600, 0700, 0800 Z − 1	5	3	3	1	2	4	6	8	4	7	3	8	54	Lagos
1300, 1600 Z − 1	0·3	0·2	0·3	0·7	0·7	3	6	3	5	3	0·5	2	25	
0700, 0800 Z − 1	7	4	3	2	4	4	4	3	4	5	2	6	48	Lagos
1300 Z − 1	0·2	0·2	0·2	0·4	1	2	2	1	1	2	0·8	0·2	11	
0700 Z 1400 Z	7 2	9 3	9 3	9 2	10 4	9 4	10 5	12 4	12 3	10 1	5 2	8 3	110 36	Accra
0830 Z − 2½ 1430 Z − 2½	3 0	4 0	10 0	15 0	11 1	9 0	8 1	5 1	6 0	7 0	9 0	9 0	96 3	Nairobi
0830 Z − 2½ 1430 Z − 2½	0 0	0 0	2 0	4 1	3 1	5 0	5 1	5 1	4 1	4 2	6 2	2 0	40 9	Nairobi
0700 Z − 1 1400 Z − 1	2 1	3 1	5 1	6 2	6 1	6 1	3 0	1 0	1 1	1 5	2 2	3 1	39 16	Leopoldville

‡ The average number of days less than 0·5.
§ Estimated values.

APPENDIX II—*continued*

AVERAGE NUMBER OF DAYS WITH CLOUD BASE 1,000 FT. OR LESS

Country	Place	Airfield or Observatory	Lat.	Long.	Height ft.	Period	Authority*
Rhodesia	Salisbury	Belvedere	17° 50′ S.	31° 01′ E.	4,780	July, 1936–June, 1946	28
South-west Africa	Walvis Bay	Windhoek	22° 34′ S.	17° 05′ E.	5,610	Mar., 1943 Apr., 1946	29
Transvaal	Johannesburg	Germiston	26° 14′ S.	28° 08′ E.	5,448	1936–45	29
Natal	Durban	—	29° 51′ S.	31° 03′ E.	42	1936–46 1940–46	29
Cape of Good Hope	Cape Town	Wingfield	33° 55′ S.	18° 32′ E.	56	1933–43	29
	Port Elizabeth	—	33° 59′ S.	25° 37′ E.	205	1942–45	29
NORTH AMERICA							
Labrador	Goose Bay	Goose	53° 20′ N.	60° 24′ W.	150	1942–45	30
Newfoundland	Gander	—	48° 57′ N.	54° 34′ W.	493	1941–45	30
Quebec	Montreal	Dorval	45° 27′ N.	73° 46′ W.	104	1941–45	30
Massachusetts	Boston	Municipal	42° 22′ N.	71° 02′ W.	29	1930–45	1
Illinois	Chicago	Municipal	41° 47′ N.	87° 44′ W.	623	1936–41	1
New York	New York	La Guardia	40° 46′ N.	73° 53′ W.	12	Jan., 1942–Apr., 1946	1
Bermuda	Bermuda	Kindley Field	32° 22′ N.	64° 40′ W.	16	Dec., 1941–July, 1946	31
Louisiana	New Orleans	Municipal	30° 02′ N.	90° 02′ W.	30	Mar., 1932–Feb., 1946	1
Florida	Miami	36th Street	25° 48′ N.	80° 16′ W.	8	Jan., 1942–May, 1946	1
SOUTH AMERICA							
Chile	Santiago	—	33° 27′ S.	70° 42′ W.	1,706	1935–36 1939–43 1935–36	38
Argentine	Buenos Aires	Morón	34° 40′ S.	58° 38′ W.	69	1941–45	34
AUSTRALASIA							
Western Australia	Darwin	R.A.A.F.	12° 26′ S.	130° 53′ E.	52	1941–45	36
Queensland	Cloncurry	—	20° 41′ S.	140° 30′ E.	618	1940–45	36
	Brisbane	Archerfield	27° 35′ S.	153° 01′ E.	85	1940–45	36
New South Wales	Sydney	Mascot	33° 57′ S.	151° 10′ E.	22	1940–45	36
New Zealand	Auckland	Whenuapai	36° 47′ S.	174° 38′ E.	85	Feb., 1942–June, 1946	37
	Wellington	Rongotai	41° 19′ S.	174° 48′ E.	10	Oct., 1943–June, 1946 Mar., 1940–June, 1946	37

* The list of Authorities is in Appendix III, p. 86.

APPENDIX II—*continued*

AT THE ZONE TIME SHOWN IN COLUMN NINE

Time	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year	Place
0800 Z−2 1400 Z−2	12 2	15 2	14 1	8 0	3 0	3 0	3 0	2 0	1 0	1 0	3 1	9 1	74 7	Salisbury
0830 Z−2 1500 Z−2	0·3 0	1 0	0·5 0	0·5 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	0 0	2 0	Walvis Bay
0830 Z−2 1500 Z−2	4 0·3	6 0·7	7 1	4 0·7	2 0·5	3 0·4	1 0·3	4 0·3	3 0·6	3 0·6	3 0·4	5 1	45 7	Johannesburg
0830 Z−2 1500 Z−2	1 0·3	1 1	1 0·1	1 0·3	0·3 0	0·2 0	0·1 0·2	0·4 1	1 2	1 1	2 1	1 1	10 8	Durban
0830 Z−2 1500 Z−2	2 0·7	4 0·4	5 0·6	6 1	7 2	5 3	4 2	3 1	3 0·9	4 0·4	3 0·1	1 0·3	47 12	Cape Town
0830 Z−2 1500 Z−2	3 0·7	5 0·7	2 1	1 0·3	1 1	0·3 1	1 0·7	1 1	2 1	2 1	3 0·7	3 0·7	24 10	Port Elizabeth
0730 Z+3½ 1330 Z+3½	2 2	4 4	3 2	2 2	4 2	5 3	1 1	4 3	3 2	2 2	2 4	4 4	36 31	Goose Bay
0730 Z+3½ 1330 Z+3½	8 9	9 9	8 6	9 7	13 6	12 5	10 4	7 3	10 6	8 8	13 10	9 9	116 82	Gander
0730 Z+5 1330 Z+5	4 4	4 2	4 3	4 3	3 0	3 1	2 0	2 0	3 1	3 2	3 3	5 3	40 22	Montreal
0730 Z+5 1330 Z+5	4 3	4 4	5 4	5 4	5 3	6 3	6 2	3 1	6 3	4 3	4 4	4 3	56 37	Boston
0730 Z+6 1330 Z+6	4 7	4 2	3 3	2 2	3 1	3 1	1 0	1 0·3	2 1	2 2	2 3	6 5	33 27	Chicago
0730 Z+5 1330 Z+5	3 3	2 2	3 3	3 2	4 3	5 1	4 1	3 1	5 3	3 3	3 2	3 2	41 26	New York
All hours	4	2	6	6	6	5	2	2	2	2	2	2	41	Bermuda
0730 Z+6 1330 Z+6	7 4	6 3	6 2	4 1	1 1	0·4 0·3	1 0·2	1 0·2	1 1	3 0·4	3 1	7 4	40 18	New Orleans
0730 Z+5 1330 Z+5	1 0·4	1 0	1 0·2	1 0·2	0·4 0	0 0·3	0 0	0 0	0 0·3	1 1	1 0·3	2 1	8 4	Miami
0900 Z+5 1400 Z+5	3 0·1	→ →	← ←	42 9	→ →	← ←	51 27	→ →	← ←	33 4	→ →	← ←	129 40	Santiago
0430 Z+4 1030 Z+4	2 2	2 2	6 2	6 5	9 4	10 6	6 5	9 6	5 3	7 3	3 1	4 1	69 40	Buenos Aires
1530 Z−9½ 2130 Z−9½	1 0	1 1	1 3	1 0	0 0	0 0	0 0	0 0	1 0	0 0	0 0	0 0	5 4	Darwin
1530 Z−9½ 2130 Z−9½	1 0	1 1	1 1	0 1	0 1	0 0	0 0	0 0	0 0	0 0	0 0	0 1	3 5	Cloncurry
1600 Z−10 2200 Z−10	2 1	2 1	1 1	1 0	1 1	2 1	1 2	1 0	1 1	2 0	2 1	2 1	18 10	Brisbane
1600 Z−10 2200 Z−10	3 2	2 1	1 1	2 1	2 1	2 1	0 1	0 1	0 0	1 1	2 1	4 1	19 12	Sydney
2100 Z−12 2400 Z−12	2 2	1 1	4 2	3 2	3 3	3 2	3 1	3 2	2 2	3 3	3 0	2 1	32 21	Auckland
1800 Z−12	4	4	3	1	3	1	1	2	2	4	6	4	35	Wellington
2400 Z−12	3	2	3	2	3	1	2	4	2	5	4	1	32	

APPENDIX III

LIST OF AUTHORITIES FOR DATA GIVEN IN APPENDIX I AND APPENDIX II

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7. Berlin, Reichsamt für Wetterdienst, Haufigkeitstabellen flugmeteorologischer Beobachtungen.
8. Koninklijk Nederlandsch Meteorologisch Instituut, De Bilt.
9. Institut Royal Météorologique de Belgique, Uccle.
10.
11. Office National Météorologique, Paris.
12. Chief Meteorological Officer, H.Q., R.A.F., MED./M.E.
13. Station Centrale Suisse de Météorologie, Zurich.
14. Budapest, Magyar Kir Orszagos Meteorológiai es földmagnességi intézet. Időjárási jelentés Magyarországról.
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17. Hamburg, Deutsche Seewarte. Täglicher Wetterbericht.
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19. Observatório Central Meteorológico do Infante D. Luis, Lisbon.
20. U.S.A.A.F. Weather Section, Air H.Q., Greece.
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29. Department of Transport, Division of Meteorology, Pretoria.
30. Air Services, Meteorological Division, Toronto.
31. Board of Trade Meteorological Station, Bermuda.
32. Serviço de Meteorologia, Rio de Janeiro.
33. Santiago Oficina Meteorológica de Chile. Carta del Tiempo and Resumen Mensuel.
34. Servicio Meteorologico National, Buenos Aires.
35. Servicio Meteorológio del Uruguay, Montevideo.
36. Department of Air, Meteorological Services, Melbourne.
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APPENDIX IV

VALUES OF THE CONVERSION FACTOR AT SELECTED STATIONS THAT ARE LIKELY TO BE EXCEEDED ON A GIVEN NUMBER OF DAYS PER YEAR

	Height	5 days per year	10 days per year	20 days per year	50 days per year	100 days per year
	ft.					
Croydon	217	1·10	1·09	1·08	1·06	1·04
Almaza	262	1·23	1·22	1·21	1·19	1·17
Khartoum	1,247	1·38	1·37	1·36	1·35	1·34
Kisumu	3,780	1·48	1·48	1·47	1·46	1·44
Nairobi	5,371	1·56	1·55	1·55	1·54	1·52
Tabora	3,800	1·49	1·48	1·47	1·46	1·45
Kasama	4,400	1·55	1·54	1·54	1·52	1·50
Elizabethville	4,026	1·52	1·51	1·51	1·49	1·47
N'Changa	4,300	1·55	1·54	1·53	1·52	1·50
Lusaka	4,177	1·53	1·52	1·51	1·48	1·47
Salisbury, Rhodesia	4,780	1·56	1·55	1·54	1·53	1·51
Johannesburg	5,080	1·57	1·56	1·55	1·54	1·52
Capetown	36	1·14	1·13	1·12	1·10	1·07
Lydda (Ramleh)	131	1·18	1·17	1·16	1·15	1·13
Dhahran (Bahrein)	5	1·22	1·21	1·20	1·19	1·16
Karachi	75	1·20	1·19	1·18	1·16	1·15
Calcutta	14	1·19	1·18	1·18	1·16	1·15
Rangoon	178	1·20	1·19	1·18	1·17	1·15
Mingaladon	100	1·19	1·19	1·18	1·17	1·15
Bangkok	10	1·19	1·19	1·18	1·17	1·16
Singapore	14	1·13	1·13	1·12	1·12	1·11
Hanoi	0	1·19	1·18	1·17	1·16	1·14
Canton	25	1·17	1·17	1·16	1·15	1·13
Hongkong	12	1·15	1·14	1·14	1·13	1·11
Shanghai	20	1·18	1·17	1·16	1·14	1·10
Tokyo	105	1·18	1·17	1·16	1·15	1·12

Note.—These conversion factors apply only to the height specified.

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