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CHARACTERISTICS OF RAINFALL  
DISTRIBUTION IN HOMOGENEOUS AIR  
CURRENTS AND AT SURFACES OF  
DISCONTINUITY

Notes on Diurnal Variation and on Relationships with Cloud,  
Wind Speed, Pressure, Etc.

By A. H. R. GOLDIE, M.A., F.R.S.E.

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# CHARACTERISTICS OF RAINFALL DISTRIBUTION IN HOMOGENEOUS AIR CURRENTS AND AT SURFACES OF DISCONTINUITY; NOTES ON DIURNAL VARIATION AND ON RELATIONSHIPS WITH CLOUD, WIND SPEED, PRESSURE, ETC.

## PART I—INTRODUCTION

In a recent paper by the writer(1)\* it is pointed out that in any empirical examination of the diurnal variations of a meteorological element a most important step is a classification of cases in the first instance according to the structure of the atmosphere in the vertical direction; a further step is a classification according to the occurrence and position of the principal heat absorbing or radiating layers, or in other words the effective "sources of heat" and "sources of cold" which govern the diurnal activity (in the vertical direction) of the atmosphere regarded as a heat engine. In the present work, which deals principally with rainfall as recorded at British Observatories and published annually in *The Observatories' Year Book*, the first step consisted of a classification in respect of the Eskdalemuir, Aberdeen and Kew districts, of the days of the three years 1922, 1923, and 1924 into days (or parts of days) marked by the passage of "warm fronts" (S), days of "cold fronts" (Q), days of "polar air" (P), and days of "equatorial air" (E)†. It will be realised that in the case of polar air some convention was necessary, as, strictly speaking, there are probably few days that are polar in the sense that the polar air extends to indefinite depths. Generally speaking, if there was some reason to believe that the cold air was 5,000 feet or more in depth and if no main front passed within the 24 hours, the day was called "polar" in the preliminary classification; also, in the same restricted and comparative sense, the term "homogeneous current" is occasionally used for brevity, covering cases where no main front passed within the 24 hours.

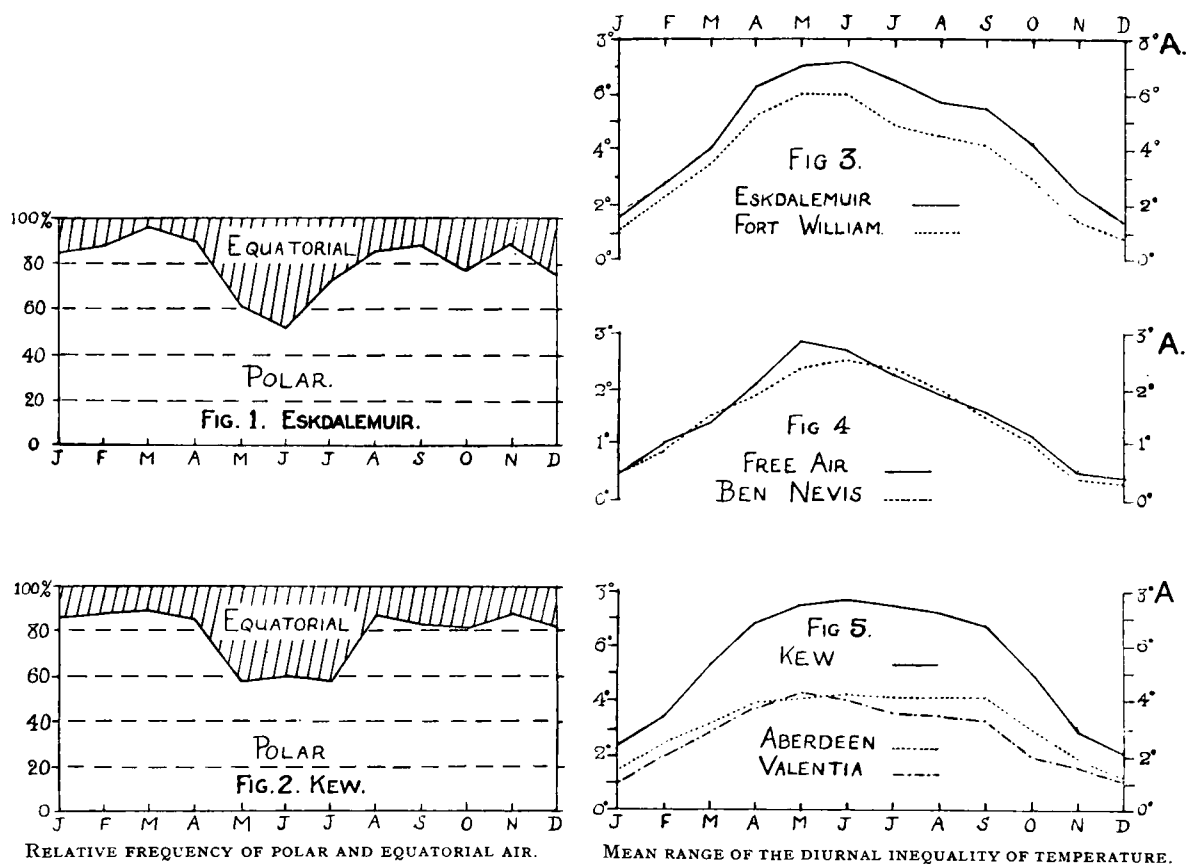
In the three years under consideration the distribution of days was as follows :—

	TYPE OF DAY		
	Polar	Equatorial	Warm and/or Cold Front
Aberdeen .. ..	599	127	370
Eskdalemuir ..	596	127	373
Kew .. ..	617	166	323

\* The numbers in brackets refer to the bibliography on p. 19.

† The general significance of this classification in matters relating to atmospheric structure, stability, etc., is fairly obvious, it is dealt with in the paper just referred to.

In order to arrive at the relative proportions of time during which each district was covered by polar and equatorial air respectively it was decided to assume as a rough average that  $\frac{3}{4}$  (S + Q) should be allotted to polar and  $\frac{1}{4}$  (S + Q) to equatorial air. On this basis Figs. 1 and 2 were constructed. To see whether the conspicuous lack of symmetry about the midsummer line was some accidental feature applying only to Eskdalemuir, or to the period under consideration, a



comparison was made with the normal annual curves (derived from long periods) for the mean daily range of temperature. This physical quantity is perhaps the one most affected by the equatorial or polar origin of the air, the daily range of temperature in the surface layers being decidedly greater in equatorial air than in polar air. The relevant curves for Eskdalemuir,\* Fort William (2), the free air between Fort William (2) and Ben Nevis, Ben Nevis itself, Valentia, Aberdeen and Kew are shown in Figs. 3, 4, and 5. The lack of symmetry in the first five cases—western stations—and the close approach to it at Aberdeen and Kew—eastern stations with a more continental type of climate, are notable. Most notable perhaps is the departure from symmetry in the case of the free air between Fort William and Ben Nevis. These curves confirm that the influxes of equatorial air reach their maxima in early summer, and that this is very apparent when we consider the upper air or western stations, though the effect is blanketed by other effects at eastern stations.

It may be further noted that whereas the table above indicates little difference between the distribution of P and E days at Eskdalemuir and that at Aberdeen, the diagrams in Figs. 3, 4 and 5 do indicate a seasonal difference suggesting that equatorial air reaches Aberdeen definitely less frequently than it does Eskdalemuir. This most certainly is the case where *only surface levels or any levels under say 2,000 feet are concerned*. Probably the part of Britain to eastward of the main north-

\* The means for Eskdalemuir Observatory are extracted from data summarized by H. W. L. Absalom and not yet published.

south mountain ridge of the country should be looked upon, relatively to the western side, as an area of "dead water," covered very frequently by a shallow layer of polar or continental air over which the equatorial air flows without getting down to ground level. This point is returned to in § 9 and is of much importance in questions such as the relative frequency of gales, questions of gustiness and wind structure, visibility, atmospheric pollution and so on. It is partly for the above reason that, for the purposes of the present paper, a day is regarded as polar only if there is reason to believe the depth of polar air to be at least of the order of 5,000 feet.

## PART II—AVERAGE DAILY AMOUNTS, DIURNAL VARIATION, ETC., OF RAINFALL IN POLAR AND EQUATORIAL CURRENTS AND AT WARM AND COLD FRONTS

### § 1—GENERAL

The tables below contain the mean daily amounts and the percentage frequency of occurrence of certain specified amounts of rainfall in polar and equatorial currents, at warm fronts and at cold fronts respectively. For practical purposes the frequency tables in the case of fronts have been put in somewhat different form from those for polar and equatorial days. [Summer includes the months April to September and winter the months October to March.]

TABLE I—MEAN DAILY AMOUNT OF RAINFALL (mm.)

	Polar air		Equatorial air		Warm front		Cold front	
	Summer	Winter	Summer	Winter	Summer	Winter	Summer	Winter
Eskdalemuir	1.56	1.71	2.34	5.78	10.01	10.33	6.09	5.92
Aberdeen ..	1.56	1.34	1.16	1.55	4.54	4.50	4.67	2.66
Kew ..	1.39	0.81	1.80	1.51	3.83	4.35	2.84	3.21

TABLE II—PERCENTAGE FREQUENCY OF OCCURRENCE OF SPECIFIED  
DAILY AMOUNTS OF RAINFALL

			Summer			Winter		
			0 to 0.1 mm.	0.2 to 0.9 mm.	1.0 mm. and over	0 to 0.1 mm.	0.2 to 0.9 mm.	1.0 mm. and over
Polar air	{	Eskdalemuir ..	59	20	21	48	21	31
		Aberdeen ..	44	23	33	49	18	32
		Kew ..	63	12	25	65	14	21
Equatorial air	{	Eskdalemuir ..	60	15	25	25	6	69
		Aberdeen ..	60	14	26	59	12.5	27.5
		Kew ..	67	11	23	55	10	35

TABLE III—RELATIVE FREQUENCY OF AMOUNTS OF RAINFALL  
(mm. PER DAY) ON DAYS MARKED BY THE PASSAGE OF FRONTS  
(S and Q days combined)

	Eskdalemuir		Aberdeen		Kew	
mm.						
0 to 1	46		152		124	
1 to 2	40		38		31	
2 to 3	27	166	31	260	30	232
3 to 4	20		17		23	
4 to 5	33		22		24	
		271		316		290
5 to 6	29		12		18	
6 to 7	23		18		17	
7 to 8	23		5		11	
8 to 9	18	105	13	56	5	58
9 to 10	12		8		7	
10 to 15		44		33		17
15 to 20		29		12		10
20 to 25		6		6		5
25 to 30		13		2		1
30 to 35		7		0		0
35 to 40		1		0		0
> 40		2		1		0
Total number of days ..		373		370		323

## § 2—RAINFALL IN POLAR AIR

The total rainfall from polar air (away from the surface trace of any discontinuity) is in general comparatively small as the table of mean daily amounts shows.

It was noted that amongst the days classified as "polar" there were a few with falls of 5mm. or more. At Kew there were 3 such days in 1922, 16 in 1923 and 16 in 1924. These were examined individually and it was found that although the surface layer of air was genuinely polar the day was in all cases one which ought strictly speaking, for questions relating to precipitation, to have been associated with a warm or a cold front, an occlusion or a secondary cold front.

At Aberdeen, as was anticipated, the number of polar days with 5mm. or more was slightly greater, being 10 in 1922, 24 in 1923 and 22 in 1924. The entrance here of an orographic effect for polar currents from between N. and E. is fairly certain; in fact the northern and eastern parts of the country seem more liable to have appreciable precipitation with polar currents than do the other parts of the country.

We may on the whole regard the tables as subject to slight correction in the direction of making polar days rather drier than indicated.

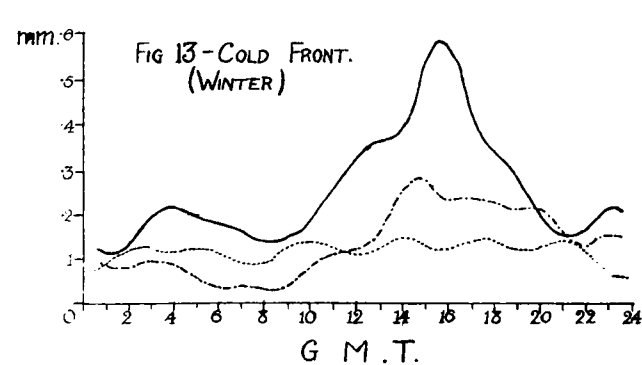
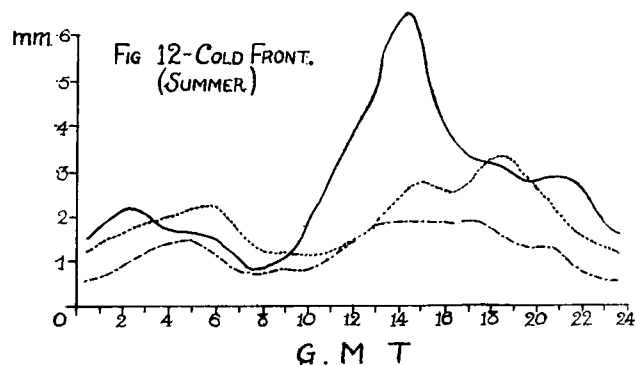
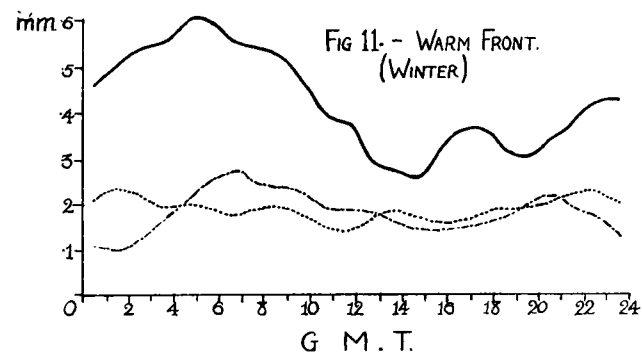
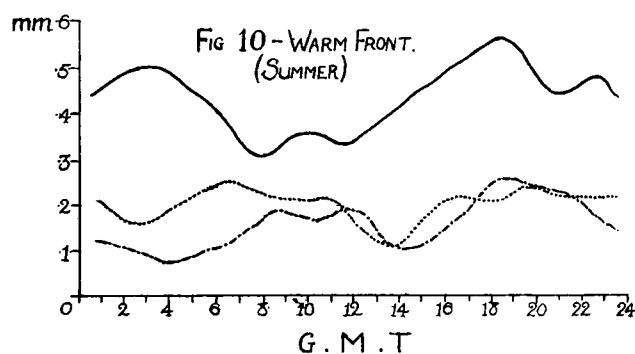
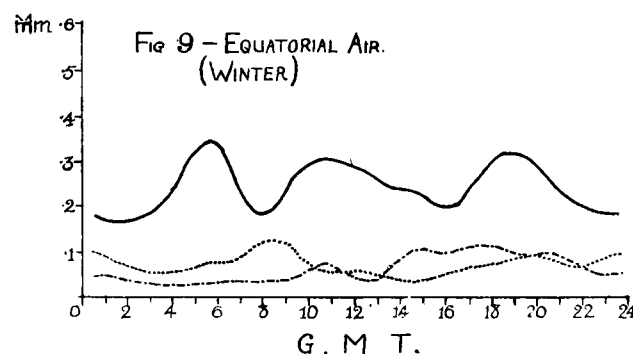
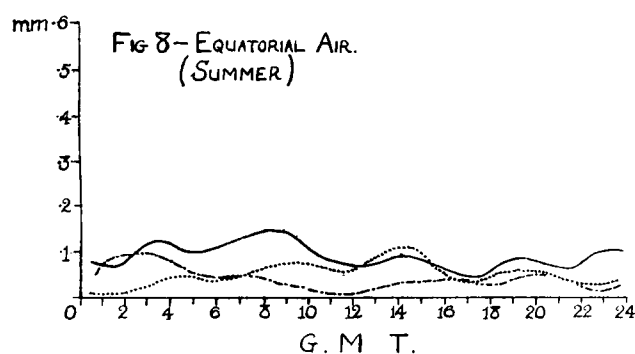
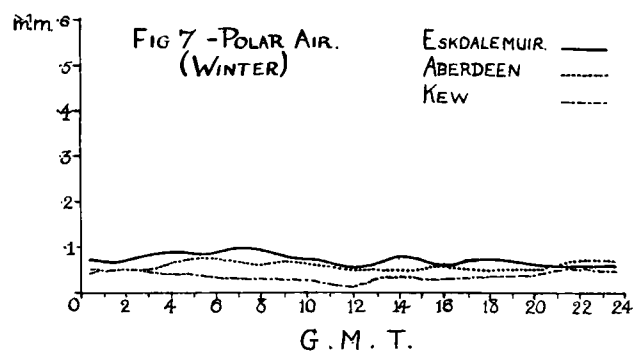
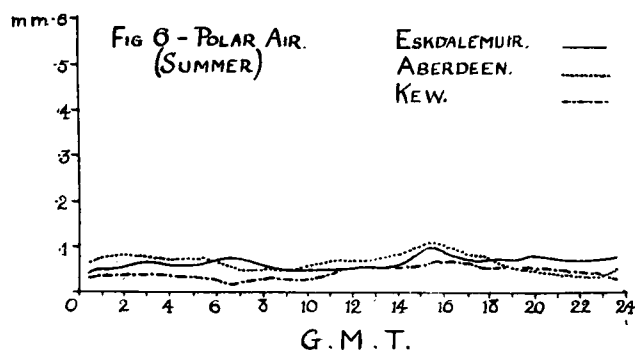
In summer there is an appreciable diurnal variation in the distribution of this small amount of polar-air rainfall (see Fig. 6), a principal maximum tending to occur at about 15–16h. and a secondary maximum sometime in the early morning hours. The distribution somewhat resembles that in cold-front rainfall, which will be discussed later; and probably the rain results from local undercutting of a mass of air which has become potentially warmer than, and therefore is in an unstable position relatively to, the air masses above or around it.

In winter (see Fig. 7) there appears to be no characteristic diurnal variation.

## § 3—RAINFALL IN EQUATORIAL AIR

The amount of rainfall in equatorial currents may vary considerably. It is obvious that a current with a high content of water and in general of considerable speed—at least in winter—(see § 9) may be expected to be capable of producing

# DIURNAL VARIATION OF RAINFALL. To face p. 6.







considerable rainfall, merely as a result of orographic conditions. The Eskdalemuir figures in the tables of mean amounts per day of equatorial air confirm this expectation.

The seasonal variation in the case of Eskdalemuir is very large, the mean amount and also the probability of an amount exceeding 1mm. being increased some  $2\frac{1}{2}$  times in winter as compared with summer. At Kew and Aberdeen, if we reckon from the frequency table, the seasonal variation, though small, is in the same direction.

It might be supposed that this seasonal variation is purely the effect of the seasonal variation in wind speed. A reference to the later sections of this work and in particular to Table XIV suggests that the matter is not quite so simple. Only at Aberdeen does it seem that the seasonal difference in rainfall from equatorial air is in fair harmony with the seasonal difference in surface wind speed. At Kew it would seem that, speed for speed, there is less rainfall in winter than in summer. At Eskdalemuir the reverse is the case, as indeed is required by the circumstance that whilst the mean daily rainfall from equatorial air in winter is increased as compared with that in summer in the ratio of 2.5 to 1 the ratio of the surface wind speeds is only 1.4 to 1. But the ratio of the upper wind speeds, viz., 2.2, does much more closely approach the ratio of the rainfalls.

In south-east England it is exceptional for a heavy fall of rain to occur in equatorial air unless in association with some not quite simple situation, such as, in particular, a very severe thunderstorm. At Kew in 1922 there were only three days of equatorial air with more than 5mm. of rain. On examination one of these cases still appeared genuinely an "equatorial" day, the second was a complex case, and the third, with nearly 10mm., was associated with a thunderstorm. In 1923 there were only two cases, July 9 and 10, both arising from one famous thunderstorm, namely that of the night of July 9-10. In 1924 there were six cases; of these on re-examination two were found to be associated with neighbouring depressions, three definitely with thunderstorms; the other was a day of winter gale with thunder reported in various other places but not at Kew.

At Aberdeen it is even more exceptional to have heavy rain in equatorial air, there having been only one case of more than 5mm. in 1922, two in 1923 and four in 1924. Only one of these cases was associated with a thunderstorm. The other six cases each showed evidence of an orographic effect (S. to SE. wind) and five of them in addition were associated to some extent with warm fronts.

In mountainous districts on the other hand, under suitable conditions, very heavy and continuous rainfall may occur in equatorial air. The ideal conditions occur in winter when the land is cold, and especially if old cold air or locally chilled air, virtually detached from the upper circulation, is lying about in the valleys and assists in forming a good smooth sliding surface over the whole mountainous region. Then the mountains, "stream-lined" by the cold air, act like a steering surface to produce what is virtually "warm-front" rainfall.

The diurnal variation of rainfall in equatorial air is somewhat complex. (See Figs. 8 and 9.) The present statistics and also personal observation of individual days in various places suggest that it is as follows:—

- (a) In winter everywhere, in summer on the west coast and in most inland districts, the tendency is for the night to be wetter than the day, for the middle of the day or early afternoon to be fine, for the rain most frequently to fall in the morning just before the surface wind rises or in the evening just after the wind falls.
- (b) At east-coast stations in summer and perhaps even in spring and autumn this regimen is subject to a complication when a sea breeze sets in. The rainfall at Aberdeen at about 13-15h. is probably produced in this way, in fact as a local squall-line effect. Similar effects, with thunderstorms, have been noted by the author on the east coast of England.

## § 4—WARM-FRONT RAINFALL

The tables suggest that the amount of warm-front rainfall is regulated largely by orographic conditions. In this respect it behaves like the rainfall on days of simple equatorial air, *but with the important difference that it has little seasonal variation*. In the case of equatorial air it was pointed out that in winter cold mountain masses with cold air lying about in the valleys may form a good sliding surface. In the case of genuine warm-front rainfall the sliding surface is already provided in the form of a wedge of polar air, and apparently there is then little room for seasonal effects to be superposed on the already great effects produced by the mountains in retarding the retreat of this wedge.

On the other hand there is an important diurnal variation in the distribution of warm-front rainfall. (See Figs. 10 and 11.) It is large and fairly regular at Eskdalemuir and becomes smaller in range and much less regular at Kew and Aberdeen.

Taking the summer curves we find at Eskdalemuir roughly equal maxima at about 3h. and 18–19h., a fairly important minimum somewhere about 8 to 11h. and a less well-marked one about 21 to 24h. At Aberdeen, however, we find less prominent effects which conceivably may have travelled from west to east across the country with a lag of some 3 to 4 hours as compared with the above effects at Eskdalemuir. At Kew we find again an evening maximum rather like the one at Eskdalemuir, *i.e.*, about 18–19h., but the other features of the curve taken in comparison with those at Eskdalemuir and Aberdeen suggest a west-east travelling effect with a lag of some 6 hours as compared with Eskdalemuir.

The winter curves on the other hand are suggestive of a non-travelling effect, which still tends to be a semi-diurnal one at Kew but approaches to a simple diurnal one at Eskdalemuir and Aberdeen. It is to be noted in passing that in winter the expectation of rain on a "warm-front" day both at Eskdalemuir and at Kew is about twice as great at about 5–7h. as it is about 14–16h. This explains why, during a cyclonic type of weather, the 7h. synoptic chart is liable to have a depressing effect on the forecaster as compared with the 15h. chart.

The evidence generally suggests that "warm-front" rainfall depends on the facility for the formation of upsliding surfaces. Its diurnal variation ought therefore to show features of the same kind as winter rainfall generally at a continental station. Fig. 14a (Paris winter rainfall) is based on data from Hann's *Lehrbuch*

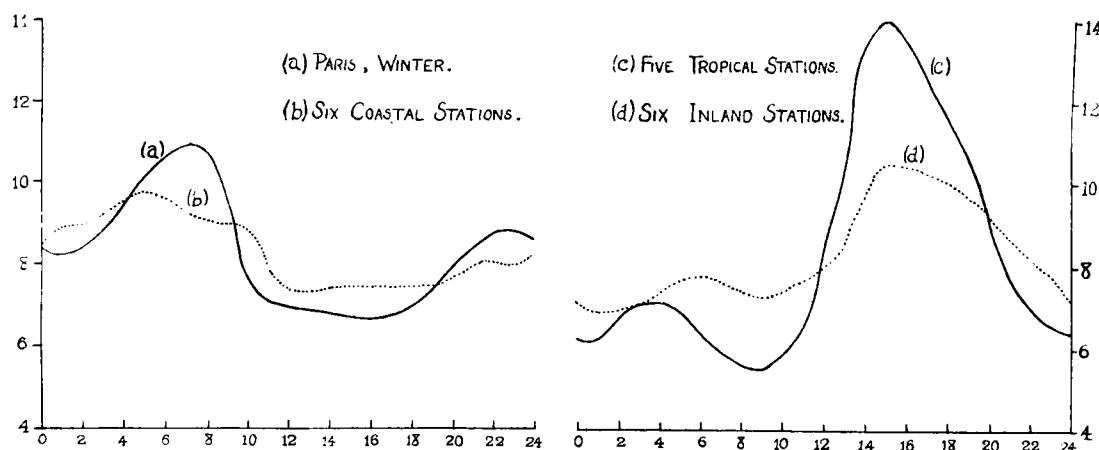


FIG. 14. DIURNAL VARIATION OF RAINFALL IN TYPICAL CLIMATES. [THE VERTICAL SCALE REPRESENTS THE PERCENTAGE OF DAILY RAINFALL, THE HORIZONTAL SCALE THE TIME OF DAY IN LOCAL MEAN TIME.]

and exhibits very clearly what these features are, namely—a principal maximum at 5–8h., a secondary maximum at 21–24h., a principal minimum or deficiency from about 11h. to 18h. and a small secondary minimum at about 2h. Fig. 14 (b) (rainfall at typical coast stations), again based on data from Hann's *Lehrbuch*, exhibits similar features. It will be asked how such a feature can be brought about. There are various possibilities—(a) The whole steering-line system may travel

with variable speed, lingering at certain times (local time) ; or (b) at certain times the upsliding surface may be improved and the intensity of the rainfall increased and/or the rain-producing area broadened.

### § 5—COLD-FRONT RAINFALL

There is once again a considerable variation with locality, but the origin of the variation is probably complex and possibly to be sought to a great extent in the proximity of a station to the west coast. At least many individual cases occur, especially in winter, in which a squall line gives considerable rainfall at Eskdalemuir but reaches Aberdeen with little of its original activity apparent. It is possible that in summer there are a few cases in which the changes proceed in the opposite sense.

The diurnal or rather semi-diurnal variation of cold-front rainfall is its most prominent feature (see Figs. 12 and 13). A principal maximum comes in the afternoon. At Eskdalemuir this maximum is sharply marked, at 14–15h. in summer and at 15–16h. in winter, the expectation of rain at these times being in summer some eight times and in winter some four times as great as at the preceding minimum, namely at 7–8h. There is a secondary maximum, much less marked, about 3–5h. At Aberdeen in summer this semi-diurnal variation is also prominent, though the various effects are delayed in time by two or three hours and considerably reduced in range ; in winter at Aberdeen there is no definite variation. At Kew, both in summer and in winter, the semi-diurnal effects are prominent but the principal maximum is much flattened as compared with Eskdalemuir, being rather in the nature of a hump from 13h. to 18h. in summer and 14h. to 19h. in winter. Rainfall at cold fronts or in polar air arises from local instability. We should therefore expect the diurnal variation to be of the same type as that of rainfall at tropical stations or in summer at inland stations. A comparison of Figs. 12 and 13 with 14 (c) and 14 (d) shows that this is indeed the case.

As to the reality of this semi-diurnal variation in matters connected with atmospheric stability there can be little doubt, but the point is rather nicely emphasized by Table IV, in which are given the frequencies with which cloud-bursts occur at different times of the day at Batavia (4).

TABLE IV—NUMBER OF OCCASIONS OF CLOUD-BURSTS, BATAVIA  
(1913–5)

Hour commencing	..	0	1	2	3	4	5	6	7	8	9	10	11
No. of cloud-bursts	..	1	4	10	6	4	4	0	2	4	3	6	3
Hour commencing	..	12	13	14	15	16	17	18	19	20	21	22	23
No. of cloud-bursts	..	3	13	9	21	22	20	26	8	13	3	5	3

## PART III—CLOUD AND SUNSHINE IN EQUATORIAL AND POLAR CURRENTS

### § 6

Generally speaking on days of polar air the effect of insolation, if it can reach the ground, is to cause cloud formation. Thus, in summer if the day starts bright it generally becomes cloudy or overcast by early afternoon. If, however, the day starts by being overcast a certain amount of clearing will usually take place.

In equatorial air, which is generally extremely stable in its lower layers, if the day in summer starts by being cloudless, the result of sunshine is generally to make the day one of more or less great heat. If, as more often happens, the day starts by being cloudy or overcast, the effect of the sun's heat is to dissipate the cloud and to lead to a bright afternoon. Thus, as a general rule, there is in summer considerably more sunshine in equatorial air than in polar air, more especially in the southern part of the country. At Kew for example, every hour from 9 a.m. to 6 p.m. has an expectation with equatorial air of at least 60 per cent of possible sunshine.

In an attempt to secure greater insight into the variation of cloud throughout

the day in summer months an examination was made of the hourly observations of cloud amount and height at Croydon Aerodrome. From this it would appear that in polar air the cloud base generally becomes lower by about 500 feet from about 8h. to 12h. then rises in the early afternoon to about its original height and then later may fall again. In equatorial air there is little change in the height of the cloud base until about 11h. after which a marked rise sets in, so that on the average it may have risen 1,000 feet by 18h., after which there is usually a decline towards the original height. Table V summarizes the sunshine data for the summer, equinoctial and winter seasons.

TABLE V—AVERAGE DAILY DURATION OF BRIGHT SUNSHINE (hours)

	SUMMER		EQUINOX		WINTER	
	Polar	Equatorial	Polar	Equatorial	Polar	Equatorial
Eskdalemuir.. ..	4.38	5.13	4.14	4.46	2.05	0.30
Aberdeen .. ..	4.53	5.71	4.18	3.09	1.83	1.12
Kew .. ..	5.65	8.63	3.70	3.23	2.05	1.20

At the equinoxes, if we except Aberdeen, there is not much difference between polar and equatorial days in the matter of sunshine. The low duration of sunshine at Aberdeen on equatorial days is probably a result of local sea fog.

In winter, conditions are markedly reversed. Equatorial air, becoming chilled on its passage overland, tends to be cloudy or misty to an extent which winter sunshine cannot clear. At Eskdalemuir in winter in equatorial air there is usually no sunshine, but much cloud or actual precipitation. The maximum of sunshine in winter is experienced on polar days of light or moderate wind.

The mean hourly amounts of sunshine are set out in Table VI.

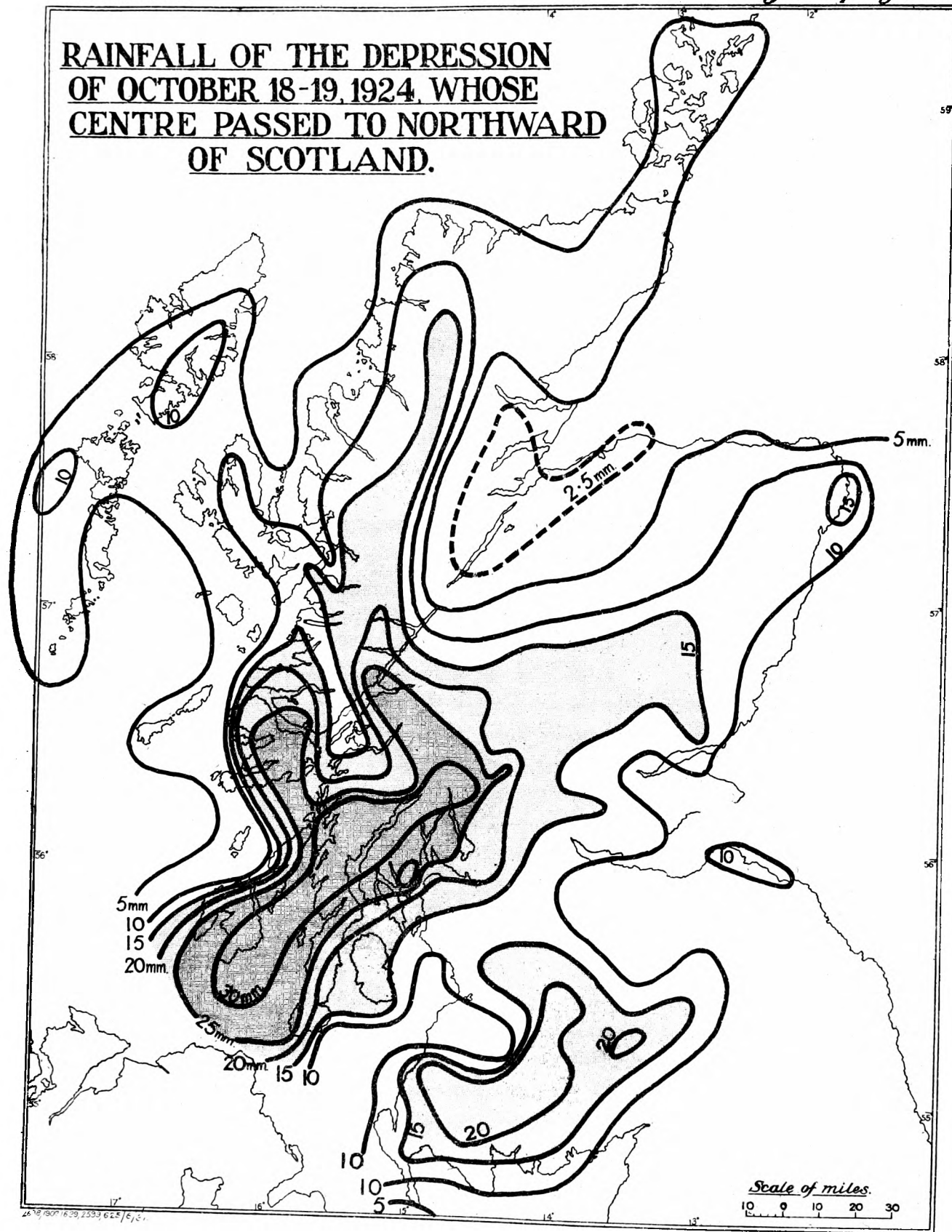
TABLE VI—DURATION OF BRIGHT SUNSHINE

Hour L.A.T.	3-4	4-5	5-6	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	19-20	20-21	Total for Day
SUMMER																			
Eskdalemuir {P.	—	.04	.15	.25	.30	.32	.35	.39	.38	.35	.33	.35	.37	.35	.26	.16	.03	—	Hr.
E. {E.	.00	.05	.17	.26	.34	.37	.41	.39	.42	.43	.44	.46	.38	.36	.34	.24	.07	—	4.38
Aberdeen .. {P.	.01	.09	.22	.24	.32	.33	.34	.35	.33	.32	.35	.36	.34	.32	.29	.21	.10	.01	4.53
E. {E.	.01	.17	.32	.32	.40	.38	.40	.41	.41	.44	.45	.43	.41	.38	.36	.28	.12	.02	5.71
Kew .. {P.	—	.04	.26	.41	.51	.50	.47	.44	.41	.44	.44	.42	.39	.34	.33	.21	.04	—	5.65
E. {E.	—	.05	.31	.49	.59	.59	.60	.67	.66	.67	.69	.67	.65	.60	.61	.53	.23	.02	8.63
EQUINOX																			
Eskdalemuir {P.	—	—	.02	.12	.27	.39	.40	.43	.45	.42	.45	.41	.35	.27	.14	.02	—	—	4.14
E. {E.	—	—	—	—	.23	.45	.51	.61	.53	.46	.39	.39	.38	.32	.12	.07	—	—	4.46
Aberdeen .. {P.	—	.00	.03	.13	.24	.36	.42	.46	.47	.44	.44	.41	.37	.25	.13	.03	—	—	4.18
E. {E.	—	—	.04	.04	.17	.28	.46	.45	.43	.36	.33	.27	.17	.08	.01	—	—	—	3.09
Kew .. {P.	—	—	.03	.13	.24	.30	.36	.41	.42	.42	.41	.37	.29	.19	.09	.03	.01	—	3.70
E. {E.	—	—	—	—	.08	.21	.30	.35	.32	.35	.39	.35	.36	.31	.16	.05	—	—	3.23
WINTER																			
Eskdalemuir {P.	—	—	—	—	.01	.13	.27	.29	.35	.33	.31	.25	.10	.01	—	—	—	—	2.05
E. {E.	—	—	—	—	—	—	—	.03	.10	.11	.06	—	—	—	—	—	—	—	0.30
Aberdeen .. {P.	—	—	—	—	.01	.06	.19	.30	.35	.37	.31	.19	.05	—	—	—	—	—	1.83
E. {E.	—	—	—	—	—	.04	.07	.18	.21	.28	.16	.10	.07	.01	—	—	—	—	1.12
Kew .. {P.	—	—	—	—	.01	.07	.23	.34	.37	.37	.33	.24	.08	.01	—	—	—	—	2.05
E. {E.	—	—	—	—	.03	.04	.14	.19	.16	.17	.17	.21	.06	.03	—	—	—	—	1.20



**FIG. 15.**

*To face page 11.*



## PART IV—LAND EFFECTS

It will be convenient to deal first with certain questions relating to “upsliding” currents, whether the upsliding takes place over mountains or over masses of cold air. The more obvious topographic effects come under this heading. In § 8, attention is then directed to certain less well recognised effects which arise with the passage of depressions over land areas.

## § 7—TOPOGRAPHICAL EFFECTS

In general, the effects of mountains on the flow of air across a country indicate in greater or less degree the following features—(i) a constriction of the isobars, (ii) a refraction and (iii) the addition of a vorticity. These features are generally to be noted on isobaric charts covering the region of the Alps (4).

Perhaps the best example of a rainfall produced orographically is that which occurs in the mountain fringes of tropical countries in the monsoon season; and in connection with a case of this sort, namely an air stream striking the Western Ghats at right angles, Simpson remarks (5)—“the ascent is naturally most sudden in the middle of the range, while at the end where the air can escape round instead of going over the top, it is less rapid.” In most of the isobaric charts reproduced by Simpson in the same paper, we have the features mentioned above. In this case we are dealing with a considerable depth of atmosphere accelerated from the cooler oceans across the mountain fringes towards the inland regions which had been strongly heated, as part of a great closed circulation, maintained by thermal processes.

As a second example of orographic effects the chart of rainfall over Scotland for October 18–19, 1924 is produced (Fig. 15). This map was prepared by Mr. R. A. Watson after selecting independently what seemed to be a typical depression with centre passing to northward of Scotland. Here, apparently, we must picture the stream lines, for the atmosphere taken as to its whole depth, as drawn together (indicating increased speed) over the mountains and as opened out over the lower parts of the country. It is evident that in arriving at a quantitative explanation, large tracts of country as a whole must be considered in the first instance, rather than the altitudes and contours of small elements of area, though annual or monthly rainfall maps do also show the superposition of quite minute local effects.

## § 8—PASSAGE OF FRONTS OVER LAND AREAS

It appears that both cold fronts and warm fronts give in general much less rain and probably very much less intense rain in the Hebrides than they do along the western seaboard of Scotland. There is not enough information available in the way of autographic records or hourly values of rainfall to enable one to go thoroughly into this point, but the daily measurements that are available suggest that the distribution of rainfall in an undistorted Atlantic cyclone is very different from that which sets in immediately land is approached. It would appear that ground friction and its diurnal variations acting on the lower cold air affect greatly the shape and slope of surfaces of discontinuity and also their rate of advance or at least the advance of their surface traces along the earth's surface, as well as their capacity for producing rain. The Monach Islands represent a site which might be expected to experience almost undistorted Atlantic conditions and it happens that a daily record of rainfall is kept at the lighthouse. An examination of this record suggests that at least some 80 per cent of the total rainfall in winter and 85 per cent in summer is definitely associated with warm or cold fronts—a much larger *proportion* than in the case of land stations.

A comparison is given in Table VII.

The table has several points of interest :—(a) If we take 750mm. of rain as the total given at their fronts by undistorted depressions, then land effects would increase this amount at Eskdalemuir by about 50 per cent and decrease it at Aberdeen by some 30 per cent and at Kew by some 50 per cent. (b) Even the total

TABLE VII—RELATIVE PROPORTIONS OF RAINFALL AT FRONTS AND IN HOMOGENEOUS CURRENTS

	Approximate annual amounts of rainfall at fronts	SUMMER		WINTER		Total annual fall <i>Mean</i> 1922-4
		Percentage of total rain falling on days of passage of fronts	Percentage of total rain falling on days of polar or equatorial air	Percentage of total rain falling on days of passage of fronts	Percentage of total rain falling on days of polar or equatorial air	
	mm.	%	%	%	%	mm.
Monach .. ..	750	85	15	80	20	911
Eskdalemuir .. ..	1060	71	29	68	32	1535
Aberdeen .. ..	520	60	40	60	40	857
Kew .. ..	385	49	51	65	35	664

rainfall from all causes at the Monach Islands is less than that from fronts of depressions alone at Eskdalemuir. (c) At places on the mainland and more especially towards the south and east the rainfall arising from causes other than fronts, constitutes a very important part of the total—something of the order of 40 per cent at Aberdeen and 45 per cent at Kew on the year as a whole. The table shewing the frequency of various amounts on days when fronts passed is of some interest in the same connection (Table III). The difference between Eskdalemuir on the one hand and Kew and Aberdeen on the other hand in regard to the relative frequency of the larger amounts (25mm. or more) is conspicuous.

The problem as it presents itself in regard to diurnal and local variations on the western seaboard of a continent is complex. Consider first of all a tongue of cold air as a flood from northward to southward underrunning the warm air; in virtue of its movement in latitude the cold air should possess relatively to the earth's surface a component from eastward; but at the same time it is being dragged above from west to east by the warm current. Next as to the capacity of a front for producing rainfall, it seems likely that this depends on (a) the velocity of the warm air across the cold or of the cold air into the warm and (b) the degree of perfection of the slipping surface between them. It is inevitable that the diurnal processes besides affecting the rainfall, affect the behaviour and subsequent history of the depression; that is, the working of the diurnal events when a depression reaches the western British or European seaboard may lead to occlusion of the warm sector and the formation of secondaries, or on the other hand may lead to a broadening of the warm sector and the deepening or increasing of the speed of propagation of the depression, according to circumstances. It has not been possible yet to explore fully this aspect of the subject.

As an example of a depression which was possibly energized by the diurnal variation may be quoted the case of October 2, 1927. As an example of one in which the warm-front rainfall over Scotland was practically cut off during the day may be taken the depression of July 26, 1927, which on the two following days seemed to be re-energized and speeded on across the North Sea.

## PART V—INTER-RELATIONS OF RAINFALL, WIND SPEED, PRESSURE AND PRESSURE CHANGE IN EQUATORIAL AND POLAR CURRENTS

### § 9—WIND SPEEDS

The mean wind speeds as measured by anemometer will be found, with certain other data, in Table XIV.

Unfortunately we do not know with much exactness the relation of the surface wind to the general drift above. The upper-air data available for the observatories



are insignificant. From an analysis of the upper-air observations at Croydon however the mean relations given in Table VIII were found :—

TABLE VIII—EQUATORIAL AIR—MEAN VELOCITIES IN M.P.H.

		Summer					Winter				
		Surface	1000 ft.	2000 ft.	3000 ft.	4000 ft.	Surface	1000 ft.	2000 ft.	3000 ft.	4000 ft.
7 h.	..	5.7	14.3	17.0	17.1	17.6	—	—	—	—	—
12 h.	..	8.7	13.3	13.3	15.2	17.1	10.0	18.0	16.5	17.5	17.5
17 h.	..	9.9	14.2	14.5	15.6	15.6	14.5	26.0	28.3	33.0	33.0

TABLE IX—POLAR AIR—MEAN VELOCITIES IN M.P.H.  
(means from ascents reaching 4,000 feet)

		Summer					Winter				
		Surface	1000 ft.	2000 ft.	3000 ft.	4000 ft.	Surface	1000 ft.	2000 ft.	3000 ft.	4000 ft.
7 h.	..	6.1	14.7	16.2	17.6	18.3	6.3	21.3	23.5	24.5	24.9
12 h.	..	10.5	14.8	15.4	16.9	17.5	9.2	16.6	20.1	21.1	20.5
17 h.	..	8.9	14.3	15.7	18.5	17.5	8.7	18.3	22.0	23.1	22.8

From these and the diurnal variation of wind speed at ground level one may deduce that at Croydon the ratios which the mean ground wind for the day bears to the drift at 2,000–4,000 feet are very roughly of the following order :—

		Summer	Winter
Polar	.. ..	.45	.32
Equatorial	.. ..	.43	.25

We do not know the corresponding figures for Eskdalemuir and Aberdeen, but the mean drift of equatorial air at Aberdeen at 2,000–4,000 feet, can scarcely be so much less than that at Eskdalemuir as is the case with the surface winds given in Table XIV. Probably the Eskdalemuir ratio is slightly higher and the Aberdeen ratio considerably lower than the Croydon one, due regard being had to relative elevations and—in the case of Aberdeen—to obstructions by mountains to westward. If we assume this we then deduce that the actual mean drifts of equatorial and polar air over Scotland and in south-east England are of the following order :—

TABLE X—MEAN DRIFT AT 2,000–4,000 FEET.

	EQUATORIAL		POLAR	
	Summer	Winter	Summer	Winter
	m./sec.	m./sec.	m./sec.	m./sec.
Scotland ..	9	20	8	12
S.E. England	8	16	7	10

These figures are only rough ones, but it is necessary in any dynamical research on the development and travel of cyclones to have some ideas as to the average speeds of polar and equatorial currents and this is one reason for placing the figures on record.

They are also of interest in indicating that *in winter* when a warm sector of a depression is freshly formed (by the retreat of the cold air letting down the warm air to surface level), *the speed in this warm air—apart from any superposed component due to wave motion—is of the order of gale force.* (See also § 11 “Mean Pressure”).

## § 10—PRESSURE CHANGES

In order of simplicity this is the point that next suggests itself for remark. In 1922 the writer (6) showed that large and rapid pressure changes occurred practically only in polar air; and that equatorial air, whether considered along a trajectory or with reference to a fixed spot in space, was subject only to slow changes of pressure. In effect it appears that large rises of pressure can come only by the insertion of wedges of colder air under warmer and that large falls can arise only from a corresponding withdrawal. In the case, however, of withdrawal it is obvious that equatorial air which was previously at some small height above ground level is let down to ground level; from this effect there may be, in the immediate region of fronts, considerable horizontal gradients, created fairly rapidly, and therefore considerable accelerations in the warm air; also appreciable apparent falls of pressure, though strictly speaking individual particles of warm air have not changed pressure, except in so far as they have undergone acceleration across the isobars towards the "front." On the other hand, there seems to be no process (other than the slow accumulation under the influence of radiation) by which appreciable rises of pressure can be produced in equatorial air which is lying on the ground. In a general way, even though the changes considered are for the somewhat long period of 24 hours, the following table bears this out. The choice of a shorter period would make the effect more evident. The over-all averages indicate that (a) in only 1 per cent of cases did equatorial air rise in pressure by more than 10mb. in 24 hours; in 4 per cent it fell by that amount (b) in 8 per cent of cases polar air rose and in 6 per cent of cases fell by a similar amount (c) in 69 per cent of cases equatorial air failed to change pressure by more than 5mb. and in only 55 per cent of cases did polar air fail similarly.

TABLE XI—PRESSURE CHANGES IN 24 HOURS  
PERCENTAGE FREQUENCIES

		Falling				Rising			
		15 & over mb.	10 to 15 mb.	5 to 10 mb.	0 to 5 mb.	0 to 5 mb.	5 to 10 mb.	10 to 15 mb.	15. & over mb.
ESKDALEMUIR—									
Equatorial	{ Summer	0	2	17	34	38	9	0	0
	{ Winter	3	3	18	41	26	3	6	0
Polar	{ Summer	1	5	10	22	35	21	4	2
	{ Winter	3	3	12	24	29	19	7	3
ABERDEEN—									
Equatorial	{ Summer	1	1	17	34	34	13	0	0
	{ Winter	3	6	16	36	26	10	3	0
Polar	{ Summer	1	4	12	25	33	18	5	2
	{ Winter	2	4	13	25	23	20	8	5
KEW—									
Equatorial	{ Summer	0	1	16	37	37	7	2	0
	{ Winter	0	13	18	33	23	10	3	0
Polar	{ Summer	0	3	13	27	32	21	3	1
	{ Winter	2	5	10	27	30	15	7	4
MEAN OF ALL—									
Equatorial	.. ..	1	3	17	35	34	9	1	0
Polar	.. ..	2	4	12	25	30	19	6	2

## § 11—MEAN PRESSURES

TABLE XII—MEAN PRESSURES AT STATION LEVEL

		Polar	Equatorial
Eskdalemuir	Summer	984	988
	Winter	986	986
Aberdeen	Summer	1009	1012
	Winter	1011	1003
Kew	Summer	1016	1017
	Winter	1016	1015

Table XII is of some interest. It indicates (a) that both Eskdalemuir and Aberdeen get slightly deeper into the polar air in winter than in summer, whilst at Kew there is little difference; and (b) that, correspondingly, the isobaric surface in the equatorial air which reaches any of the three places is a lower one in pressure (*i.e.*, initially from a higher elevation) in winter than in summer and that this is very markedly more so in the case of Aberdeen than in the case of Eskdalemuir or Kew.

The differences in the relative and actual pressures at Kew as compared with the Scottish stations are in the direction to be expected if one remembers that polar air in flooding southward over our Islands is subjected to an increase of pressure (and a decrease of speed); and that in equatorial air the isobaric surfaces slope downward towards the north.

The source of supply of equatorial air is the sub-tropical high-pressure belt and the above table is in agreement with the fact that this belt is further south in winter than in summer. *Also, the further this air has to change its latitude (so long as it does not mix with air of other sources) the greater must become the westerly component of its velocity (relative to the earth's surface)—a result which again accounts for the high velocity of equatorial air in winter (see § 9).*

In the main wind speeds and especially gales, even abnormal gales, are accounted for in this way, *i.e.* (a) change of latitude of a mass of air, combined with (b) no mixing with air coming from the other direction, and in conformity with (c) conservation of moment of momentum (of the whole moving masses) about the axis of the earth. Then in turn, the larger and more rapid pressure changes are brought about by the relative motions of two or more large masses of air, each more or less homogeneous in itself. The "head" or "potential" of pressure necessary to maintain the general movement of the atmospheric engine against frictional losses is provided by the slow accumulation, under the influence of radiation, of air within the polar calottes, and over continental areas in winter.

## § 12—RELATIONS BETWEEN PRESSURE, RAINFALL AND WIND SPEED

It is rather remarkable that the annual mean relationships between pressure, rainfall and wind speed are of closely similar nature for the three Observatories. It is not to be expected that in individual cases there would be close correlation between these elements, and indeed there is some suggestion that such general relationship as exists is not in any case linear. For the following reasons it is not to be expected that, even when many cases are grouped together at random, very definite relationships should necessarily emerge:—

- (i) *Pressure ( $p$ )*. The initial pressure at which equatorial or polar air starts from rest (or nearly so) in its "home" latitude will vary somewhat and the latitude of its "home" will also vary. On this account alone data for  $p$  will show some scatter.
- (ii) *Rainfall ( $R$ )*. We must think of  $R$  as in some way a measure of vertical movement, and we have thus at once the difficulty that we record the upward movements only, *i.e.*, we have no negative values, though taken all together the positive and negative should balance. All the negatives are grouped as zeros on the zero line of rainfall and we cannot say how much allowance should be made for them.
- (iii) *Wind speed ( $W$ )*. The mean surface wind for the day is not a satisfactory measure of drift in the mean direction; many hours may be calm or quite at variance with the general upper wind.

Dot diagrams connecting pairs of these elements suggested that if the more extreme cases were excluded it would be reasonably possible in most cases to fit straight lines to the data and thus to arrive at equations connecting the data at least in the more usual cases. These equations are given below. For the reasons already mentioned the third equation in each group is not the same as would be derived from the first and second.

TABLE XIII—AVERAGE NUMERICAL RELATIONS BETWEEN PRESSURE, RAINFALL AND WIND SPEED

	Equatorial days	Polar days
Aberdeen	$\begin{cases} R = \cdot 055 (1035 - p). \\ W = \cdot 09 (1050 - p). \\ R = \text{Const.} + \frac{1}{10} W. \end{cases}$	$\begin{cases} R = \cdot 06 (1035 - p). \\ W = \cdot 09 (1060 - p). \\ R = \frac{2}{3} W. \end{cases}$
Kew	$\begin{cases} R = \cdot 10 (1035 - p). \\ W = \cdot 09 (1050 - p). \\ R = \text{Const.} + \frac{1}{10} W. \end{cases}$	$\begin{cases} R = \cdot 05 (1035 - p). \\ W = \cdot 09 (1050 - p). \\ R = 1 \cdot 0 - \frac{1}{10} (W - 4)^2 \\ (= \frac{1}{2} W - \frac{1}{10} W^2). \end{cases}$
Eskdalemuir	$\begin{cases} R = \cdot 16 (1010 - p). \\ W = \cdot 13 (1020 - p). \\ R = \frac{1}{2} W. \end{cases}$	$\begin{cases} R = \cdot 07 (1010 - p). \\ W = \cdot 09 (1040 - p). \\ R = \frac{2}{3} W. \end{cases}$

When due allowance is made in pressure for the difference of altitude of Eskdalemuir (equivalent to some 25 millibars) as compared with Kew and Aberdeen, and in the rainfall for orographic effects, it is remarkable how much the  $R$ ,  $p$  and  $W$ ,  $p$  relationships run in all three cases in the same direction, namely, in one which suggests:—

- (a) a cessation of rainfall or upward air movement as sea-level pressure tends to 1035 mb.
- (b) a cessation of horizontal air movement for a sea-level pressure which for polar air is about 1060 mb. and for equatorial air is about 1050 mb. These may be regarded as theoretical "potentials" from which movement is acquired or to which movement may lead.

The second result is an explicable one if we may take it that the greatest pressure attainable in our latitude is related to the initial pressure and speed with which the invading polar air leaves its "home" latitude; and in turn the lowest pressure is related to the highest in the sense of a return oscillation, but probably of greater amplitude. Knowing that the mean pressure in this latitude is some 1014 mb.\* we deduce that the lowest ordinarily attained should be well below 968 mb., probably somewhere about 950 mb. The next point is that:—

- (c) taken in relation to pressure both rainfall and wind speed in polar air follow virtually the same equations at Eskdalemuir, Aberdeen and Kew.

On the other hand we find—

- (d) in equatorial air the relative ratios of rainfall at Eskdalemuir, Kew and Aberdeen for a given sea-level pressure are as 16 : 10 : 5·5 and those of wind speed are as 13 : 9 : 9. There is here in regard to rainfall evidence of the working of orographic effects in increasing rainfall at Eskdalemuir and lowering it at Aberdeen; whilst in regard to wind speed we have merely the difference of the exposures (to equatorial currents) of the west and east sides of the country, the velocities at Eskdalemuir being in these cases about 50 per cent higher than at Kew or Aberdeen.

The statistics used in this section are summarized in various ways in Tables XIV to XIX.

TABLE XIV—MEAN WIND SPEEDS

		Eskdalemuir		Aberdeen		Kew	
		E.	P.	E.	P.	E.	P.
Surface speeds (m./sec.)	Summer	4·5	4·2	2·8	3·6	3·2	3·2
	Winter	6·4	4·0	3·8	4·0	4·0	3·3
Ratios, winter to summer	Surface speeds	..	1·4	1·0	1·4	1·1	1·2
	Upper winds	..	2·2	1·5	2·2	1·5	2·0
	Daily rainfalls	..	2·5	1·1	1·3	0·8	0·8

\*Though high pressures, being more persistent than lows, weight this unduly from the present point of view.

TABLE XV—MEAN DAILY RAINFALL (mm.) IN RELATION TO WIND SPEED

Mean speed (m./sec.)			0 to 2	2 to 4	4 to 6	6 to 8	8 to 10	10 to 12	12 and over
Eskdalemuir ..	{ Summer	{ E.	0.9	1.3	2.4	5.6	3.3	2.2	5.4
		{ P.	0.9	1.9	1.5	4.2	4.0	1.7	
	{ Winter	{ E.	0.0	2.2	4.3	6.6	11.0	19.5	
		{ P.	0.8	0.7	1.4	3.4	3.0	5.1	
Aberdeen ..	{ Summer	{ E.	3.3	0.6	0.6	—	—	—	—
		{ P.	1.8	1.2	1.7	1.5	2.5	16.5	
	{ Winter	{ E.	0.0	0.6	0.6	4.0	—	—	
		{ P.	0.2	1.2	1.4	2.5	4.1	3.4	
Kew ..	{ Summer	{ E.	1.3	1.5	2.3	5.1	—	—	—
		{ P.	[or 0.1 0.7	0.8 1.1	0.9 1.1	0.8 0.2	if certain 0.0	exceptional	
	{ Winter	{ E.	0.9	1.6	1.1	2.3	—	—	
		{ P.	0.5	1.0	0.8	0.6	or 1.2 if certain 0.1	exceptional	

TABLE XVI—MEAN DAILY RAINFALL (mm.) IN RELATION TO PRESSURE

Mean pressure (mb.) at station level			970 & lower	970 to 980	980 to 990	990 to 1000	1000 to 1010	1010 to 1020	1020 & over
Eskdalemuir	{ Summer	{ E.	8.3	5.5	2.6	1.3	0.1	—	—
		{ P.	2.5	3.8	1.4	0.6	0.0	—	—
	{ Winter	{ E.	4.8	13.2	4.3	0.7	0.0	—	—
		{ P.	4.7	2.6	1.4	0.8	0.3	—	—
Aberdeen	{ Summer	{ E.	—	—	—	1.8	2.5	0.7	0.1
		{ P.	—	—	4.3	1.9	2.2	0.8	0.2
	{ Winter	{ E.	—	—	—	2.5	0.7	0.4	0.2
		{ P.	—	2.5	2.1	3.0	1.8	0.9	0.7
Kew	{ Summer	{ E.	—	—	—	5.0	4.7	1.7	0.1
		{ P.	—	—	—	[or 2.8 if certain exceptional cases are omitted]	2.8	0.5	0.1
	{ Winter	{ E.	—	—	—	3.7	1.6	0.9	0.2
		{ P.	—	—	2.9	1.6	1.1	0.9	0.4

TABLE XVII—MEAN DAILY WIND SPEED (m./sec.) IN RELATION TO PRESSURE

Mean pressure (mb.)			970 & lower	970 to 980	980 to 990	990 to 1000	1000 to 1010	1010 to 1020	1020 & over
Eskdalemuir	{ Summer	{ E.	5.3	6.2	4.2	4.2	2.9	—	—
		{ P.	4.3	4.7	4.1	3.7	2.6	—	—
	{ Winter	{ E.	3.5	9.3	8.6	4.0	0.8	—	—
		{ P.	6.2	4.9	4.4	3.9	3.5	—	—
Aberdeen	{ Summer	{ E.	—	—	—	3.4	2.8	2.6	3.2
		{ P.	—	—	5.1	3.8	3.5	3.5	3.0
	{ Winter	{ E.	—	—	—	4.7	3.9	3.2	2.2
		{ P.	—	6.2	5.2	4.5	4.4	4.1	3.1
Kew	{ Summer	{ E.	—	—	—	5.9	3.9	3.2	2.4
		{ P.	—	—	—	3.8	3.8	3.0	2.7
	{ Winter	{ E.	—	—	—	4.6	3.8	4.4	3.2
		{ P.	—	—	5.2	3.7	3.8	3.4	2.7

TABLE XVIII—EQUATORIAL AIR—RAINFALL IN RELATION TO MEAN  
PRESSURE AND PRESSURE CHANGE IN 24 HOURS

Mean Pressure (mb.)	Mean amounts (mm.) of rain per day.				Percentage of dry days (0.2 mm. or less).			
	Pressure falling >5 mb.	0-5 mb.	Pressure rising 0.5 mb.	>5 mb.	Pressure falling >5 mb.	0-5 mb.	Pressure rising 0-5 mb.	>5 mb.
ESKDALEMUIR								
<970	7.4	6.1	—	—	0	0	—	—
970 to 980	11.5	11.0	3.2	—	17	0	0	—
980 to 990	2.4	2.8	3.4	2.2	27	50	40	50
990 to 1000	2.2	1.0	0.6	2.2	29	52	78	40
>1000	—	—	—	—	—	—	—	—
ABERDEEN								
<990	—	—	—	—	—	—	—	—
990 to 1000	5.8	1.0	0.4	—	0	50	40	—
1000 to 1010	2.3	1.8	2.1	1.2	10	70	50	40
1010 to 1020	0.1	1.3	0.3	0.7	82	67	75	70
>1020	0.0	0.1	0.0	0.0	100	100	100	100
Kew								
<990	—	—	—	—	—	—	—	—
990 to 1000	3.1	3.9	—	—	0	0	—	—
1000 to 1010	3.4	2.3	1.5	—	0	30	25	—
1010 to 1020	1.8	0.9	0.9	0.3	79	71	70	33
>1020	0.0	0.4	0.0	0.0	100	88	100	100

TABLE XIX—POLAR AIR—RAINFALL IN RELATION TO MEAN  
PRESSURE AND PRESSURE CHANGE IN 24 HOURS

Mean pressure (mb.)	Mean amounts (mm.) of rain per day.				Percentage of dry days (0.2 mm. or less).			
	Pressure falling >5 mb.	0-5 mb.	Pressure rising 0-5 mb.	>5 mb.	Pressure falling >5 mb.	0-5 mb.	Pressure rising 0-5 mb.	>5 mb.
ESKDALEMUIR								
<970	8.5	5.6	2.7	2.2	0	17	31	25
970 to 980	5.0	4.2	3.0	2.7	37	23	30	36
980 to 990	2.1	2.1	0.7	1.2	52	39	65	53
990 to 1000	1.2	0.5	0.6	0.9	63	75	77	66
>1000	0.4	0.2	0.3	0.3	40	79	100	78
ABERDEEN								
<990	3.6	5.3	7.9	2.1	40	0	20	67
990 to 1000	3.2	2.6	2.5	1.9	28	45	42	38
1000 to 1010	1.0	2.2	2.5	2.0	38	39	33	46
1010 to 1020	0.8	0.6	1.1	1.1	64	62	53	44
>1020	1.2	0.4	0.3	1.0	62	75	85	53
Kew								
<990	3.3	—	—	1.3	0	—	—	50
990 to 1000	5.4	2.3	1.0	0.9	0	33	40	60
1000 to 1010	1.6	2.4	1.3	0.7	48	33	56	66
1010 to 1020	0.8	0.7	1.0	1.2	75	74	64	68
>1020	0.9	0.3	0.1	0.2	42	79	86	82

## CONCLUSIONS

The main conclusions of this *Memoir* are that a cyclonic depression cannot be regarded as some travelling agent which sprinkles precipitation independently of the nature of the region over which it is passing or independently of the time of day. In an earlier paper by the present writer (1), it is mentioned that "at least over the British Isles, phenomena of the warm-front and cold-front descriptions either show preferences as to the times of their occurrence for certain periods, or are more conspicuous when they pass within these periods." After the publication of this earlier paper and the preparation of the greater part of the present one there was brought

to the writer's notice work by A. Schmauss (7), in which, from a consideration of Continental data and by entirely different methods, the conclusion is reached that "the onset of a depression does not occur with equal probability at any hour of the day; there exist critical periods which lie near to the turning points of the ordinary daily pressure oscillation." This peculiarity of depressions may therefore be taken as established beyond reasonable doubt.

The most notable result of the present paper is that the rainfalls occurring at warm fronts and cold fronts have characteristic semi-diurnal variations of very considerable amplitude, variations which are much more marked than those in rainfall occurring in homogeneous equatorial or polar currents. The variations are in neither case symmetrically semi-diurnal, but if one averages up the two types of rainfall the times of maxima correspond roughly to those of minima of barometric pressure and vice versa in the average semi-diurnal variation of pressure. If the resonance theory of the semi-diurnal oscillation of pressure be accepted, there is some difficulty in seeing why the normal pressure variation should be associated so markedly with the variations of rainfall in the locality of discontinuities and less so, if at all, with the rainfall of days which are subject to less disturbance of a local character. To facilitate comparison with the pressure variations characteristic of different types of days reference may be made to the representative diagrams given in the writer's paper on "The structure of the atmosphere as affected by diurnal variations." It may then be said at once that the variation of rainfall on days marked by the passage of discontinuities appears to bear no relation whatever to the variation of pressure characteristic of such days. Actually of the Eskdalemuir pressure curves available, those, which, when reversed, resemble most closely the rainfall curves are (a) the pressure variation on bright days of equatorial air in summer which, reversed, resembles the variation of rainfall on cold-front days in summer; (b) the pressure variation on cloudy days of equatorial air in summer which, reversed, resembles the variation of rainfall on warm-front days in summer; (c) the pressure variation on cloudy days of equatorial air in winter, which, reversed, resembles the variation of rainfall on warm-front days in winter.

It would therefore appear that the diurnal variation in the rainfall at fronts is controlled primarily—

- (a) in the case of cold fronts by the thermo-dynamical working of insolation and radiation on the more or less clear warm sector in advance of the front, and
- (b) in the case of warm fronts by the corresponding effects of insolation and radiation on the cloudy warm air above the upsliding surface.

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