DECIMAL INDEX
551.582 (412+413)

METEOROLOGICAL OFFICE

CLIMATOLOGICAL SERVICES (Met O 3)

CLIMATOLOGICAL MEMORANDUM No. 53

THE CLIMATE OF KINCARDINESHIRE AND EAST ANGUS

by

F.H. Dight OBE, B.Sc.

G.3468/LG/3/66/125

PREFACE

This memorandum is one of a series dealing in some detail with the differing climates of various regions of Scotland. The boundaries of the regions as delineated in the areal maps are artificial, but for convenience they coincide with areas for which the Macaulay Institute for Soil Research are currently engaged on preparing a series of Memoirs of the Soil Survey of Great Britain. This memorandum, and the others in the series are being used as a basis for the chapters on "Climate" in the corresponding memoirs of the Soil Survey.

It is hoped that the design of the memoranda is such as to be useful to a wide variety of interests. The approach is not purely one of presenting in consolidated form the data available in the Meteorological Office, but in some degree a more dynamic approach in relating cause and effect has been adopted.

The policy has been to build the climatic picture round the analysed data available from climatological stations which have been in operation over a long period of years and to supplement this information not only from the observations at stations now no longer operative but also by the inclusion of data from the many stations that have come into being during the past 10 years or so and for which a useful summary can now be made. Data for stations outside the nominal boundaries of the regions have been exploited where it is considered that these add representative detail to the picture or where it gives an important lead, especially in the absence within the boundaries of the region of a station with a similar exposure.

The periods on which the climatic tabulations have been constructed are given. The averages of the major elements, temperature, rainfall and sunshine (unless otherwise stated) are those for the standard 30 or 35 year periods currently in use but for the climatological summaries the observations up to and including those for 1964 have normally been utilised. When a station has suffered breaks in its records, either partially or completely and where these breaks are considerable, or otherwise appear important, a suitable annotation is made. It is relevant to remember that at meteorological offices at defence establishments and civil airports the weather watch is continuous for most or all of the 24 hours and the staff have opportunities for noting phenomena which the observer at a climatological station might miss.

In order to keep the tabulations within reasonable limits, full climatic data are normally given for long term stations, but for subsidiary stations some items, even where available, e.g. the number of rain days, are not given unless they show significant variations or there are other specific reasons for not presenting the figures as comparative data. Annual averages which are normally large, e.g. numbers of rain days, days of ground frost etc. are rounded off to the nearest whole number.

In accordance with official Meteorological Office policy, temperatures are usually given in degrees Celsius. Practically all the temperature data are recorded however, in degrees Fahrenheit and for this reason °F have been retained for individual extreme readings.

These maxima and minima were originally recorded in whole degrees °F obtained by throwing to the odd so that a recorded 32°F could be any value from 31.6°F to 32.4°F, and a recorded 33°F could be any value from 32.5°F to 33.5°F and so on. Recorded values of 32°F are important in relation to the frequency of frost. An air frost is currently defined as a day when the screen minimum fell below 32.0°F (0.0°C) but until 1st January 1963 a screen minimum which was recorded as 32°F (i.e. 32.4°F or less) was counted as a day of air frost. The average frequencies are therefore a little higher than they would be had the present more precise definition been operative.

/Statistics

Statistics of "ground frost" given in the climatological tables also need some qualification. Formerly a "ground frost" was recorded when the near surface temperature fell to 30.4°F and this criterion applies to practically all the observations on which the statistics are based. "Ground frosts" are not now recorded, the term being reserved for use in forecasting only. In their place grass minimum temperatures below 0.0°C are recorded. The average number of "ground frosts" given in the tabulations based on the former criterion are comparable among themselves and are not yet significantly affected by the new procedure.

The following key is applicable to the headings of the climatological summaries:-

R	=	a day with 0.01 in. or more of rain (09-09h GMT)
W	=	" " " 0.04 in. or more of rain
S	=	" " " snow or sleet falling
SL	=	" " " snow lying (snow covering one half or more of the ground representative of the station at 0900h GMT)
H	=	" " " hail
T	=	" " " thunder heard
F	=	" " " fog at 09h GMT
AF	=	" " " air frost)
GF	=	" " " ground frost) - for criteria see above
G	=	" " " gale

In the areal maps, stations are indicated as follows:-

■ = Meteorological Office stations

▲ = Co-operating climatological stations

● = Rainfall stations

For purposes of comparison with other localities and regions, the following publications may be consulted:-

M.O. 735	Averages of temperature for Great Britain and Northern Ireland 1931-60	H.M.S.O.
M.O. 743	Averages of bright sunshine for Great Britain and Northern Ireland 1931-60	"
M.O. 635	Averages of rainfall for Great Britain and Northern Ireland 1916-50	"
M.O. 421	Averages of Humidity for the British Isles	"
M.O. 488	Climatological Atlas of the British Isles	"

*Climatological Memoranda No.38, 1931-60 Averages of temperature and sunshine for stations not included in M.O.735

*No.40, Frequencies of snow depth for given ranges at selected stations in Scotland

* Available from Meteorological Office (Met O 3c) Bracknell

/*Hydrological

*Hydrological Memoranda

No. 1 (Revised) Part II - Monthly averages of rainfall for Scotland and Northern Ireland, 1916-50, for MWR stations.

" 26 Rainfall, 1916-50, over the areas of Solway, Ayrshire and Clyde

" 27 Rainfall, 1916-50, over the areas of Kintyre and S.W. Islands, Add, Awe, Etive, Lochy and Linnhe

" 28 Rainfall, 1916-50, over the areas of Shield, Alsh, Maree, Inner and Outer Hebrides and Laxford

" 29 Rainfall, 1916-50, over the areas of Naver, Thurso and Wick Water to Conan

" 30 Rainfall, 1916-50, over the areas of Beauly and Ness, Banff, Moray and Nairn

" 31 Rainfall, 1916-50, over the areas of Dee and Don, N & S. Esk and Tay

" 32 Rainfall, 1916-50, over the areas of Forth, Lothians and Tweed

* Available from Meteorological Office (Met O 3c) Bracknell

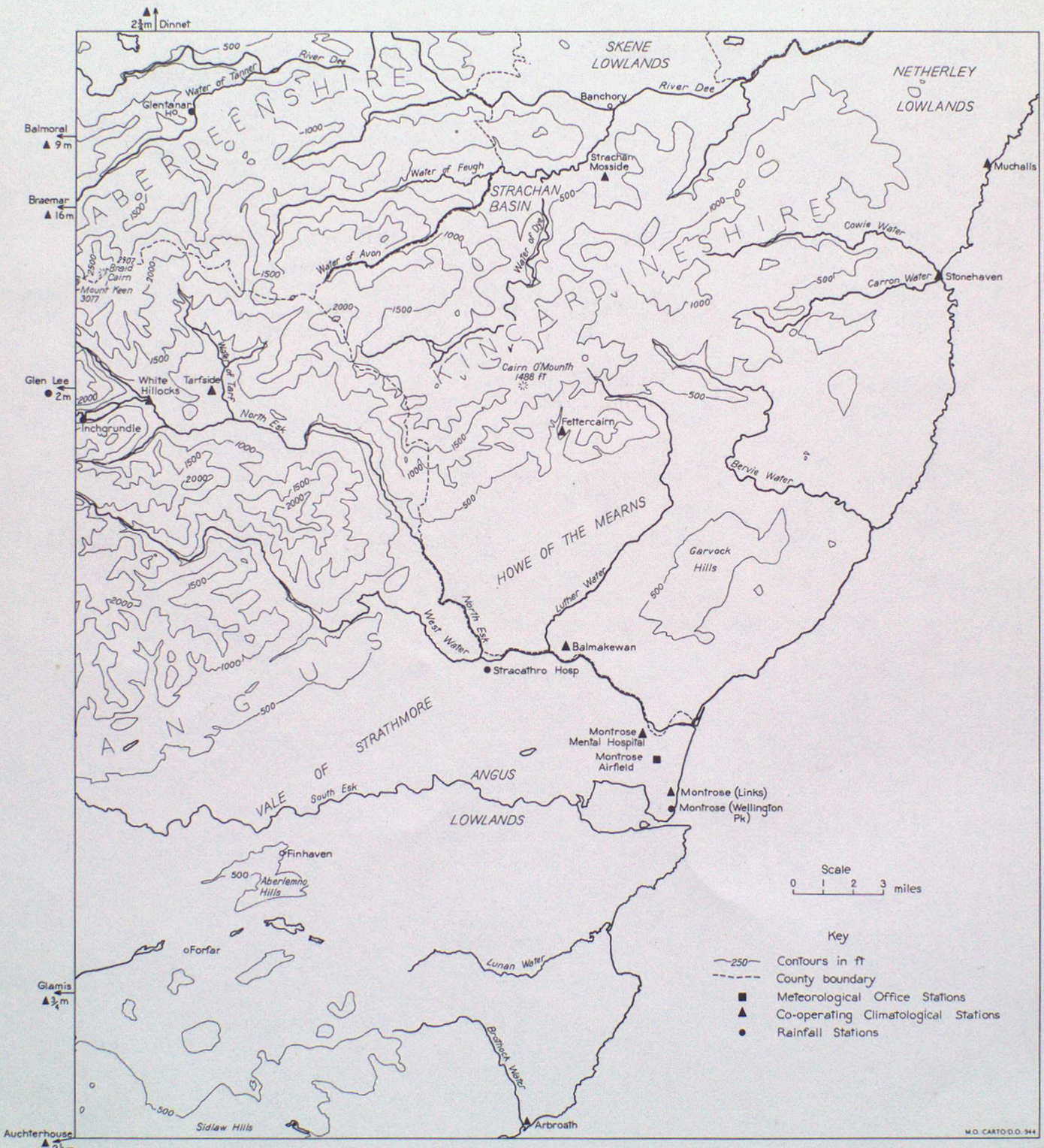


Fig 1. Kincardineshire and East Angus.

THE CLIMATE OF KINCARDINESHIRE AND EAST ANGUS

by F.H. Dight, OBE, B.Sc.

Introduction

The region to be reviewed, delineated in Fig. 1, covers some 880 square miles of Kincardineshire and Angus and a small area north of the river Dee in Aberdeenshire. The great Highland Boundary Fault running southwest from Stonehaven devides the terrain into two major physical regions of highlands and lowlands.

North of the Great Fault, low lying areas, below about 500 ft., are restricted to the Dee valley and part of the Skene and Netherley lowlands, with the Feugh valley forming a broad basin (the Strachan Basin) within the Grampian foothills. The whole of this northern section is drained by the eastward flowing River Dee with its northeastward flowing tributary "waters" of Tanar, Feugh, Avon and Dye. Immediately to the south of these lowlands is the much more extensive area of the Grampian Foothills backed to the west and southwest by the Grampians themselves rising to some 2000 to 2500 ft. and to around 3000 ft. in the Braid Cairn and Mt. Keen - the highest points in the area reviewed.

South of the Great Fault is the wide value of Strathmore extending from Perth to Stonehaven bounded to the south by the Sidlaw Hills but otherwise rarely rising above 500 ft. except for small local outcrops until the ascent into the foothills is reached. The part of the vale under consideration, approximating to an obtuse angled triangle in shape, divides naturally into three sub areas:- in the north, the Howe o' the Mearns with its gentle slopes and altitudes between 150 and 500 ft. and bounded to the east by the Garvock Hills; centrally are the extensive Angus lowlands, forming a broad, gently rolling plain generally below 400 ft. The southern section comprises the Forfar-Lunan channel and the irregular rolling country of the Sidlaw foothills rising to around 900 ft. The major drainage system is that of the North Esk river (marking the boundary between Angus and Kincardine) with its tributaries the West Water and Tarf all flowing mainly in a southeasterly direction. The area to the north, forming the apex of the triangle, is drained by the Carron, Cowie and Bervie Waters with a mainly easterly flow. The courses of the North Esk river complex like that of the Dee are marked by wide valleys or glens cutting deeply through the foothills from the main mountain mass. The glens associated with the North Esk open to the east or southeast unlike those of the Dee which open to the north or northeast. Sizeable glens, again opening to the east, have also been carved by the northern system of "Waters". Only the eastward flowing South Esk river and the Lunan Water which drain the southern basal section of the triangle have no extensive re-entrants.

General Climate

The climatic survey of the region may conveniently be pursued in close conformation with the natural features and land forms. Nearly one half of the area - the wide Vale of Strathmore and the associated extended coastal belt - comprising the major lowland area obviously suggests itself as a basic "unit". This section has a northeast to southwest orientation, and thus differs from the secondary lowland area of the Dee valley and the Strachan basic which have a mainly northerly aspect and is limited in respect of its exposure to the influence of the sea. Both areas have much in common climatologically and it will largely suffice to elaborate significant variations as between one region and the other due mainly to the differing exposures.

North of the Great Fault line, lie the foothills to the Grampians, an irregular, almost "corrugated", indented area of rising ground, turning sharply to the west north of Stonehaven. In this area a changing climate is associated with increasing altitude and changing aspect. Local variations of the general climatological pattern tend to be sharp. It will be convenient

/ to

to consider the foothills as taking over from the lowlands at altitudes of around 500 to 600 ft. - the 500 ft. contour aligns very closely with the accepted position of the Fault Line - and rising to round about the 1500 ft. level. The harsh Highland mountain climate rapidly gains complete control with increasing altitude above 1500 ft. and a description of its chief features will be found in the final section of this memorandum.

Broadly, the region may be considered as in the southeastern sector of the peripheral zone of the North Atlantic depression systems, many of which are, or are quickly becoming, occluded. Atlantic "lows" approaching the Hebrides, chiefly in autumn and early winter, bring eastern Scotland wholly into their circulation but the situation can be quickly retrieved by a surge of pressure from western European high pressure systems. Another seasonal phase, tending to recur in Spring, (and of greater frequency in recent years), is the development of an anticyclone in the more northerly latitudes bringing easterly winds to much of the region.

A pleasant climate, in relation to the latitude, is enjoyed, by and large, in the lowland and coastal belt from Stonehaven to beyond Forfar for which a fairly high frequency of westerly winds is largely responsible. It is moderately dry and quiet, with a good proportion of bright days; hard winter frosts are fully compensated by some warm days in late spring and early summer. Easterly winds, on the other hand, have a definite nuisance value. The Dee valley area however, has a more bleak climate, with the Buchan promontory providing only limited shelter from winds from the north.

Winds

Isobaric charts of Scotland based on long period mean sea level pressures reveal an almost northwest to southeast orientation of the isobars over the region in most months as opposed to the more general southwest to northeast trend. The anomaly is less marked with the feeble mean pressure gradients indicated for May to July. This orientation suggests a high frequency of west to northwest winds indicating that the area is often in lee of the high ground to the west.

Some indication of the wind regimes is given by the diagrams in Fig. 2. The Auchterhouse (760 ft.) anemometer* although raised some 50 ft. above ground level was backed by a sizeable hill immediately to the north and was thus not fully representative for winds from about due north and due south. The Montrose airfield (22 ft.) was very near the sea and unusually open to the sea breeze.

The predominant winds are from the west to northwest sector over the northern part of the area, but back rather more definitely westerly in the central zone. But even in the south of the region where southwesterlies might have easy access via the southwestern limb of the Vale of Strathmore, the west wind is at least as frequent as that from the southwest over the year and "has the edge" over the southwesterlies in autumn and winter.

The absence of a marked predominance of southwesterly winds where the topographical orientation appears to invite a concentration of these winds over the lowlands and foothills is, in part at least, due to the apparent reluctance of depressions to cross the formidable mountain barrier. Approaching western Scotland on the usual northeasterly course, the depressions temporarily take a more northerly track to the Hebrides, there finally to resume the original northeasterly movement but often only after tracking eastwards off northern Scotland. The winds are thus prone to veer more decisively from south to west, rather than to be maintained between south and west for the longer period to be expected if the system had not been diverted.

Winds from between north and east, which prevail at times in spring and early summer, are invariably cold; mostly they bring showery weather - which the more southerly foothills may escape - and are often the prelude to spring frosts, but as the season progresses the easterlies tend to be associated with "haar". Easterly sea breezes develop easily on the coast on the warmer days of the year and in the most propitious circumstances penetrate as far as the

* Station ceased Dec. 1964

/ southern

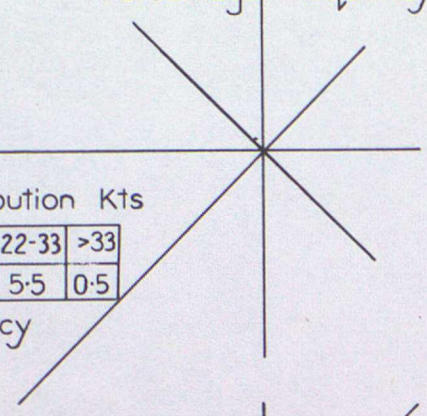
WIND ROSES

MONTROSE AIRFIELD

Observations at 01, 07, 13, 18 h G.M.T
Sept 1939 - Aug 1945

All Speeds — Percentage frequency of occurence

YEAR

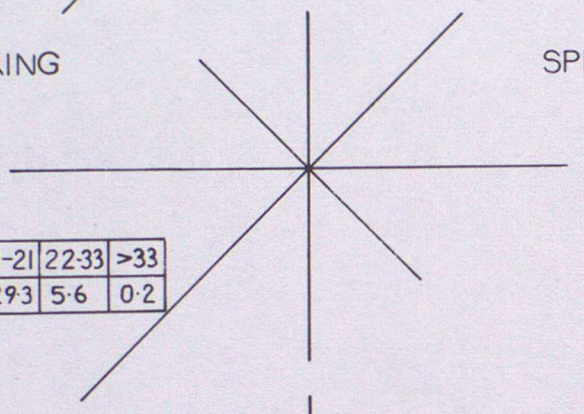


Speed Distribution Kts

Calm	1-10	11-21	22-33	>33
5·3	62·3	26·5	5·5	0·5

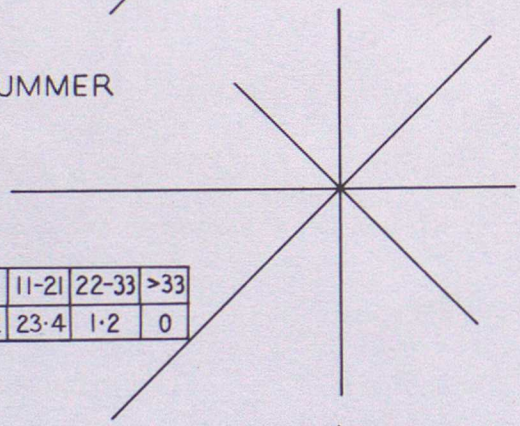
% age frequency

SPRING



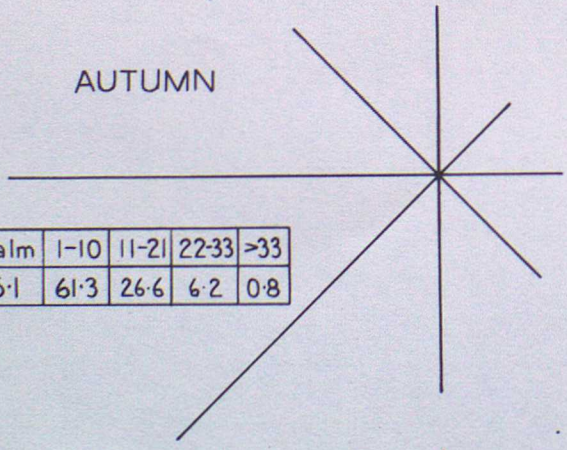
Calm	1-10	11-21	22-33	>33
4·9	60·0	29·3	5·6	0·2

SUMMER



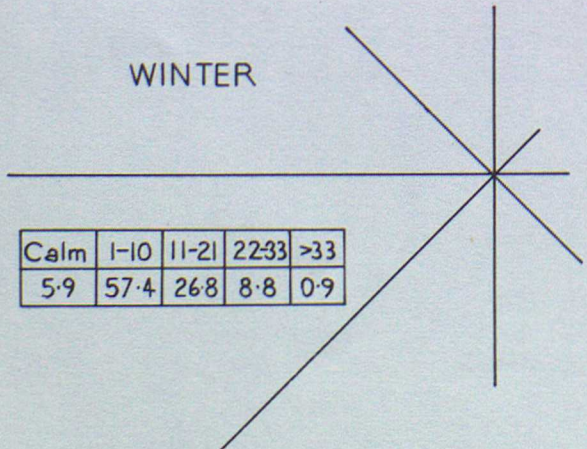
Calm	1-10	11-21	22-33	>33
5·2	70·2	23·4	1·2	0

AUTUMN



Calm	1-10	11-21	22-33	>33
5·1	61·3	26·6	6·2	0·8

WINTER



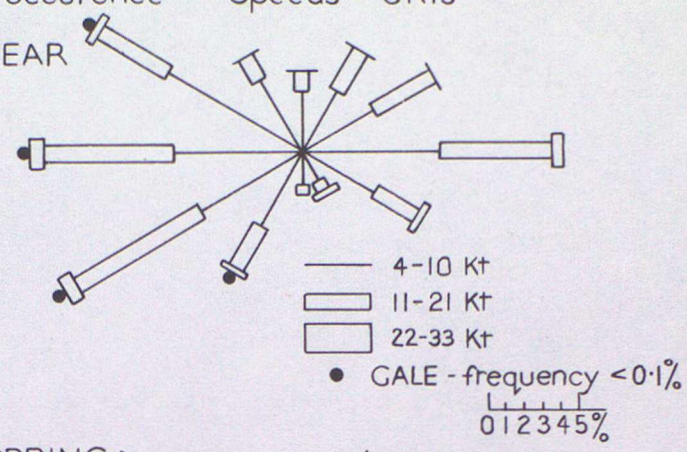
Calm	1-10	11-21	22-33	>33
5·9	57·4	26·8	8·8	0·9

AUCHTERHOUSE

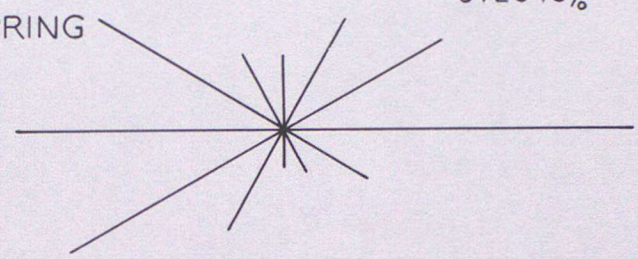
Anemograph Hourly values
Jan 1960 - Dec 1964

Speeds > 3 Kts

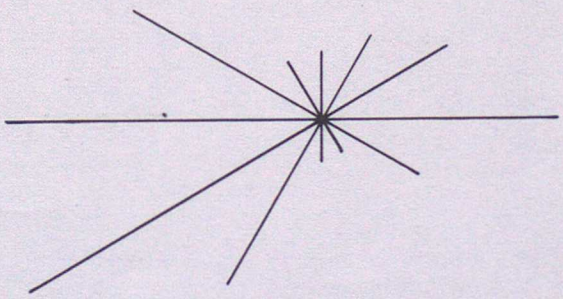
YEAR



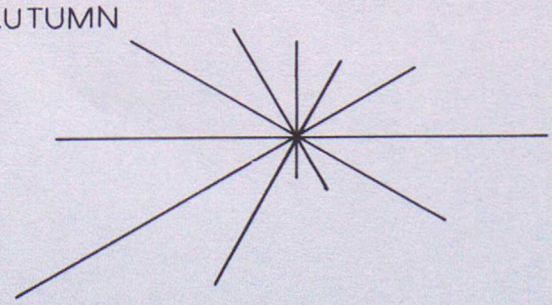
SPRING



SUMMER



AUTUMN



WINTER

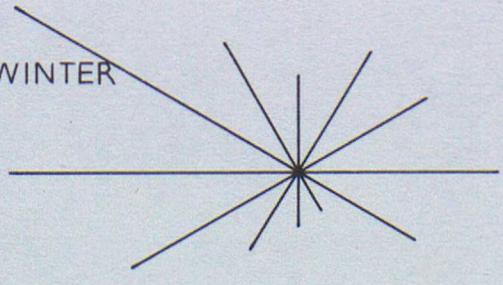


Fig 2.

M.O./CARTO/D.O./944

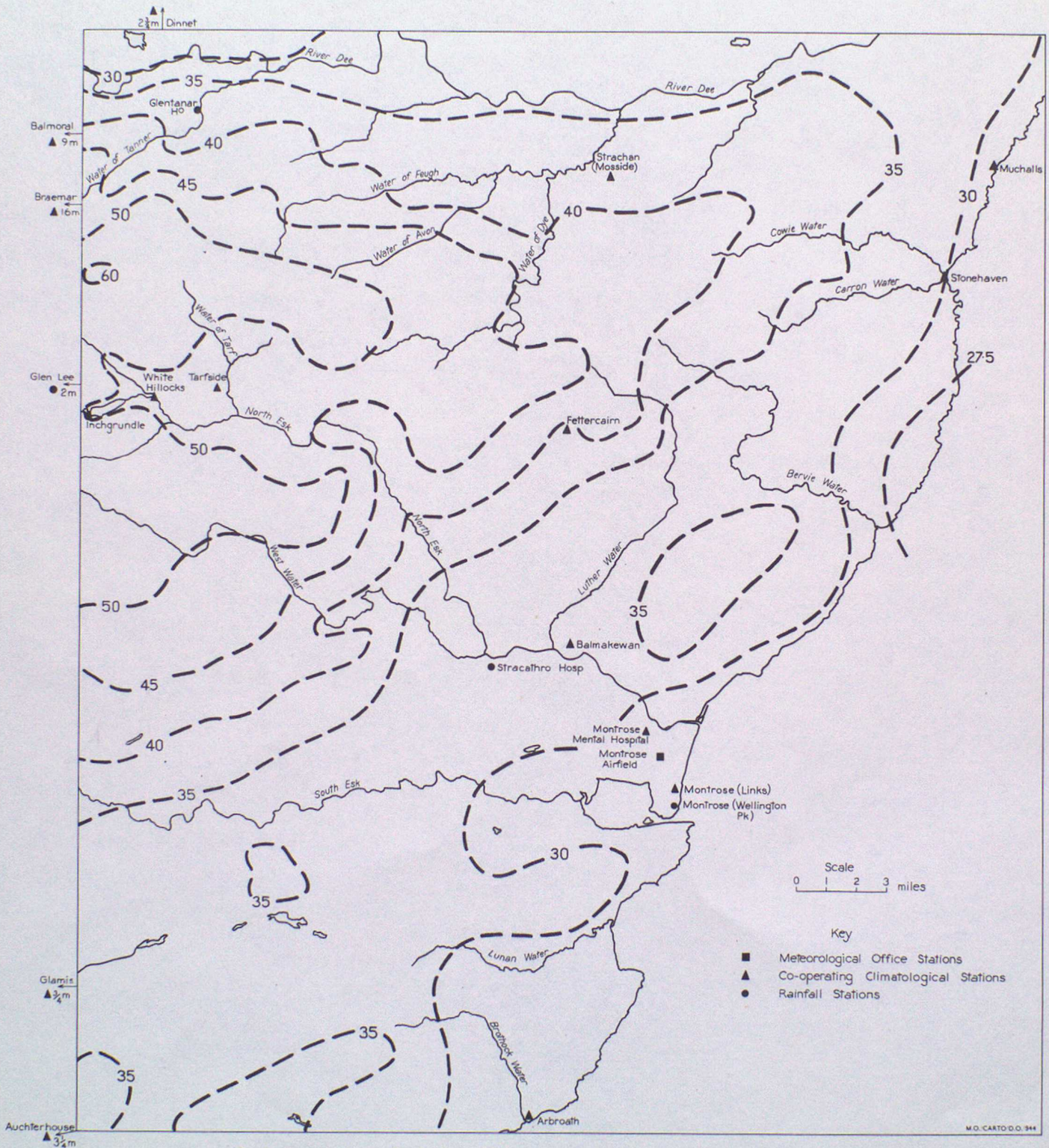


Fig 3. Average Annual Rainfall (Inches) for the period 1916-50 over Kincardineshire and East Angus

southern foothills before dying away. They frequently bring in fog from the sea. The spring and summer diagrams for Montrose (Fig. 2) clearly indicate the extent of the combination of these "easterly" winds.

Gales

A startling paucity of gale force winds inland over the lowlands and foothills and extending even to the coast is a vitally significant feature shown by the analyses of the relevant data. The Balmakewan area, for example, shows up as one of the least windy districts in the United Kingdom - almost on a par with the inland districts of central-southern and eastern districts of England - in Shellard's[1] computations of the extreme wind velocities likely to occur over various periods of years.

This categorical statement needs some qualification for at least some of the deep re-entrant valleys although the affected areas are probably quite small. Such glens form convenient funnels where considerable increases in wind speed may occur locally when the general wind blows parallel to the valley, and the effect may be strengthened by the development of valley winds encouraged by large near surface temperature differences associated with the proximity of the mountains. Thus at Gensaugh, near Fettercairn, situated at the entrance to the glen oriented approximately along the direction of the predominating winds (NW-SE), the average gale frequency is as high as 13 days per annum (Table 9) but with the increase in northeasterly winds in March and April the gale frequency then becomes lower than for the period June to September.

The worst gales come from the W or NW quarter usually behind a cold front and there may be violent squalls. Gales associated with the advance and passage of warm fronts and occlusions from the south are usually much less gusty. Very occasionally a deep disturbance moves to the northern North Sea giving northerly gales over East Scotland to which the Dee valley is most exposed. Such was the disastrous gale of 31st January 1953 which laid low extensive areas of forest in Deeside (and elsewhere). A gust speed of 101 m.p.h. at Dyce is a fair indication of the violence of the assault in the north of the region and along much of the exposed coastal zone.

Rainfall

Thirty to thirty five inches is a fair estimate of the average annual rainfall over the whole area south of the Great Fault, except over the localised outcrops of higher ground, and over the Dee valley and the Skene and Netherley lowlands (Fig. 3), which latter lie within the rain-shadow of the Grampians. From about 27 in. over the driest section - the coastal strip between Stonehaven and Bervie Water, - the annual average increases to 60 in. or so on the higher peaks. This increase in rainfall with increasing altitude is much less rapid than in any other area in Scotland, so that much of the foothills and the contained river valleys receive only 40 to 45 in.

The seasonal distribution pattern is very consistent over the whole region at all altitudes up to approximately 750 ft., as will be seen from Table 1. The dry period in the first half of the year, common to much of eastern Scotland, is well marked; there is a sharp drop in the average figures from January to February, and the five months to June together account for only about one-third of the year's total. March is normally the driest month in most districts, but May, prone to showery weather, is the least reliable of the drier months. A sharp increase of an inch or more in July gives a secondary maximum peak in the rainfall curve preceding the autumnal maximum of October and November.

October is marginally the wettest month at altitudes around 1000 ft. but at this altitude all four months through to January have much the same expectation of substantial precipitation. July and August are also liable to substantial rainfalls. The change in the pattern over the higher foothills towards the mountain district pattern, having a more uniform distribution

/ through

Table 1

Averages of Monthly and Annual Rainfall (inches) - Period 1916-50

	Ft.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
MONTROSE (Wellington Park)	17	2.50	1.96	1.67	1.84	2.30	1.81	2.88	2.76	2.65	3.12	2.82	2.48	28.79
ARBROATH (Springfield Park)	95	2.28	1.86	1.60	1.55	2.13	1.65	2.63	2.44	2.49	2.89	2.52	2.21	26.25
BRECHIN (Stracathro Hosp.)	120	2.87	2.25	1.89	2.12	2.55	1.99	3.20	3.13	2.90	3.50	3.29	2.94	32.63
MUCHALLS	210	2.56	1.87	1.73	1.93	2.35	1.87	3.06	2.65	2.71	3.19	3.06	2.77	29.75
GLAMIS CASTLE	200	3.43	2.45	1.99	1.86	2.63	1.95	3.10	3.39	2.86	3.56	3.42	3.15	33.79
GLENTANAR HSE.	553	3.55	2.50	2.28	2.47	2.73	2.16	3.51	3.44	3.25	4.07	3.81	3.59	37.36
FETTERCAIRN (Glensaugh)	560	3.43	2.61	2.34	2.53	3.04	2.34	3.82	3.63	3.47	4.17	4.02	3.59	38.99
INCHGRUNDLE	885	4.85	3.46	3.07	3.11	3.66	2.52	4.60	4.60	4.20	5.35	5.04	4.99	49.45
GLEN LEE (Stables)	1545	4.90	3.25	3.15	3.20	3.65	2.85	4.55	4.60	4.20	5.40	5.25	5.00	50.00

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Table 2

Average Number of Days of Rain and Snow

	ARBROATH (50-51 yrs)				FETTERCAIRN (14-17 yrs)				MUCHALLS (14-15 yrs)			
	R	W	S	SL	R	W	S	SL	R	W	S	SL
Jan.	15.7	11.1	4.3	3.0	17.9	12.6	8.7	10.6	16.6	11.8	4.8	6.1
Feb.	13.7	9.1	4.3	3.3	16.8	12.5	8.7	9.5	15.3	10.9	6.1	6.6
Mar.	13.1	9.1	3.4	1.8	16.4	11.7	4.6	5.8	14.4	10.0	3.1	2.6
Apr.	13.1	7.8	1.1	0.1	15.4	11.1	2.7	0.8	12.8	9.1	1.1	0
May	13.1	9.2	0.2	0	15.6	11.5	0.5	0	13.6	9.2	0.3	0
Jun.	11.9	8.5	0	0	14.6	10.5	0	0	11.9	9.1	0	0
Jul.	14.7	11.1	0	0	16.0	12.6	0	0	16.5	12.7	0	0
Aug.	14.9	10.8	0	0	18.9	14.5	0	0	17.5	13.3	0	0
Sep.	12.6	9.2	0	0	16.3	11.3	0+	0	15.4	10.8	0	0
Oct.	15.4	10.8	0.2	0+	17.4	12.5	0.4	0+	15.2	11.3	0.6	0
Nov.	15.1	11.2	0.7	0.4	18.4	13.5	1.1	0.8	17.3	13.0	0.9	1.1
Dec.	15.9	11.1	2.4	1.6	20.4	15.4	5.0	5.6	18.1	13.4	3.1	3.3
Year	169	119	16.6	10.2	204	150	31.7	33.1	185	135	20.0	19.7

	MONTROSE (LINKS) (35-38 yrs)				BALMORAL (51 yrs)			
	R	W	S	SL	R	W	S	SL
Jan.	15.1	11.3	4.0	2.2	20.9	14.2	7.7‡	14.7
Feb.	13.1	8.9	3.8	2.4	18.2	11.9	6.9	14.0
Mar.	13.0	7.7	3.0	1.1	18.0	12.1	6.5	10.7
Apr.	13.4	8.7	1.5	0.2	18.4	11.3	4.5	2.6
May	12.8	9.4	0.1	0	17.2	11.4	1.3	0.3
Jun.	11.5	8.3	0	0	15.4	9.9	0.2	0
Jul.	14.9	10.9	0	0	17.9	12.2	0	0
Aug.	14.2	10.3	0	0	18.1	11.9	0+	0
Sep.	12.5	8.9	0	0	17.8	11.8	0.1	0
Oct.	15.3	10.6	0.3	0	20.0	13.6	1.5	0.8
Nov.	15.7	11.4	1.0	0.2	20.0	13.7	3.3	4.1
Dec.	15.7	11.0	2.3	1.0	20.9	14.7	5.9	10.6
Year	167	117	16.0	7.1	223	149	37.9	58

0+ denotes less than 0.05

‡ No Reports 1950-58

through the year, may be attributed to the fact that the rain-shadow effect is only noticeably effective at some distance to leeward of the main mass of high ground.

Measurable rain falls on some 170 to 180 days annually near the coast, the average frequency increasing northwestwards to about 200 days in the foothills and thence rather more rapidly with increasing altitude to an estimated figure of about 230 days at heights of approximately 1500 ft. with an average annual rainfall approaching 50 in. At greater altitudes the number of rain days (with 0.01 in. or more) probably does not increase significantly but the duration and thus the amount of rain per rain day is larger and the number of days with 0.04 in. or more increases in proportion to the number of rain days.

Dry and Wet Spells

Periods of a week or so without measurable rain among the foothills, in the Vale and in the northern lowlands occur some four or five times annually on average but the dry spell does not generally exceed nine to ten days without one or two days bringing a measurable if, for most practical purposes, insignificant fall. The wonderful summer of 1955 gave 28 consecutive dry days at Fettercairn in July.

Really wet days with over one inch of rain average about four per year with some tendency to occur most regularly in July or August, suggesting an association with the recognised rainy spell of "the Lammas Flood" period in the Borders and East Lothian. Falls of over two inches are rather rare, but the 60 year period at Arbroath contains one entry of 3.09 in. in September 1927.

Snow

According to A.B. Thomson (private communication), over the main lowland area the percentage of the average annual precipitation which falls in the solid form increases from about 6% to 7% in the south of the region to about 10% in the north. In view of the relatively low rainfall and the absence of any really high ground (Thomson's basic calculations refer to sea level) much of the lowlands area is by no means snowy. Over a wide coastal zone snowfall is, in fact, not very troublesome since much of the snow which does fall melts quickly with winds off the sea, and this is particularly true of the Montrose-Arbroath area where the long term average number of days of snow cover per season is around 16 days as compared with rather more than 20 days at Muchalls. Moving towards the foothills, where the maritime effect is lessened, the days of snow lying increase.

Much of the snow is brought by cold air masses from the north. Unlike much of the Vale of Strathmore, the Dee valley has little shelter from this direction and the snowfall, whether from frontal snow belts or the frequent showers from the Buchan area, is augmented by the hill barrier to the south. A mainly northern aspect and distance from the sea are both unfavourable to a quick melting of snow cover. Thus at Strachan (395 ft.) in the severe winter of 1962-63, snow cover, mainly to a depth of five to six inches persisted for 68 days from 27th December to 4th March, which was not markedly less than the persistence at Balmoral (927 ft.). The Howe of the Mearns falls into an intermediate category, receiving the "spill-over" from the northern section reinforced by the showers brought in with the northeast winds.

Thus the lower foothills have an average of some 33 days of snow falling and an equal number of days of snow lying (vide Table 2 - FETTERCAIRN). Increasing altitude is associated not only with increased annual precipitation but also with an increased percentage falling as snow. Thomson's computation suggests a percentage of 15% at about 1100 ft. so that with the increased persistence a reasonable figure at around 1000 ft. is approximately 50 to 55 days of both snow falling and snow cover. At 1500 ft. snow cover probably averages some 80 days per winter season. However, wide variations from the average occur in individual years and at altitudes of 500 to 1000 ft. in the 1962-63 season snow cover persisted for 75 to 90 days. January and February are the most snowy months.

/ Snow

Table 3

Percentage Frequency of Various Depths of Snow and Days with Snow-lying

Station	Height ft.	Period	Depth in inches					Days with snow lying		
			2 or less	3 - 6	7 - 12	13 or more	Max depth	Total	Average per winter *	
									Short Period	Long Period
			% frequency							
FETTERCAIRN	560	56/57-62/63	44.5	30.2	20.8	4.5	17	245	35.0 (7)	33.1 (14)
MUCHALLS	210	" "	71.6	24.1	1.4	2.9	24	137	19.6 (7)	19.7 (14)
MONTROSE	16	" "	83.4	15.8	0.8	0	12	120	17.1 (7)	7.1 (35)
ARBROATH	95	" "	76.3	22.5	1.2	0	9	80	11.3 (7)	10.2 (50)
BALMORAL	927	46/47-62/63	49.3	24.6	17.1	9.0	36	949	55.9 (17)	57.8 (51)

* The number of winters is given in brackets

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Snow depths in Scotland have recently been examined by Burns[2] mainly covering the seasons 1956-57 to 1962-63 and some extracts from his tabulations are given in Table 3. Comparison of the average number of days of snow lying over the recent seven winters (taken as Nov.-April) as given by Burns will be seen to be in very close agreement with the annual averages of snow lying in Table 2 (reproduced in Table 3) for the same stations with:- (a) records over about 15 years (e.g. Fettercairn) and (b) the very long established stations of about 50 years (e.g. Arbroath). The annual average for Montrose for an intermediate period of around 36 years is, however, very definitely lower. The decrease must be attributed to the lack of snowfall during the pre-war period of mild winters of the later 1920's and through the 1930's. At Balmakewan, well inland from Montrose, during the period 1930-36, the annual average number of days of snow lying was only seven. Well into the foothills accumulations of snow are often enhanced, and their persistence thereby increased, by snow blown from higher levels and by reductions in wind speeds caused by local topographical features especially with formations lying across the more usual snow bearing winds as instanced by the frequent blocking of the Fettercairn-Banchory road in the vicinity of Cairn Mount.

Temperature

The range of mean monthly temperature through the year is very near 11°C over the lowlands and a degree or so more well inland into the foothills (Table 4). The coldest month is January with a mean value of around 2.5°C at low levels as compared with about 14°C in July, the warmest month.

Afternoon maxima in July average around 18°C and are not very sensitive to altitude change whereas winter maxima, normally more than 11°C lower are more affected by both altitude and situation.

The long winter nights, coupled with the tendency for little or no wind, bring average minimum temperatures in January down to freezing point or below over all but a narrow coastal strip and February means are only fractionally higher. In the foothills and enclosed glens it is not until later in March that the mean night minimum rises above freezing point. Even at mid-summer in the western part of the region the average night is up to 1.5°C colder than it is in the lowland coastal areas.

Extreme Temperatures

Examination of the extreme recorded temperatures reveals an absolute range of 95°F (53°C) from the coldest winter night to the warmest summer afternoon in the very long term records for the foothills and associated glens whilst large absolute ranges of about 80°F are on record in the flat lowlands. Summer maxima of 80°F or more have occurred widely in all four months May to August from the coast to the 1000 ft. level. A maximum of 86°F has occurred at Arbroath and it is most likely that higher temperatures have occurred away from the coast (cf. 88°F (31°C) at Balmoral in 1911 and 1915). Extremes of winter cold in the glens like those in the upper reaches of the North Esk and those of the Waters of Dye, Feugh and Tanar, take temperatures below 0°F (-18°C) and probably down to about -10°F (-23°C) in very severe spells (cf. Braemar -17°F (-27°C) in 1895 and -13°F (-25°C) in 1955 - both in February). In the lowlands 4°F (-16°C) has been registered at Arbroath and 10°F (-12°C) at Stonehaven. Some 20°F (11°C) of overnight air frost is commonplace throughout the region at the height of the frost season. The average date of the first frost of the winter season over the lowlands even near the coast is 18th-20th October and that of the last 7th May. The frost season is obviously longer in the re-entrant valleys and is progressively prolonged with increasing altitude until at around 1000 ft the average dates are 23rd August and 3rd June, and no month is entirely immune from frost.

An interesting feature of these intensely cold nights during quiet fine weather, more particularly in "glen" situations, is the extremely rapid rise in temperature during the forenoon taking the mercury up to near freezing point, and sometimes above, by midday. It is the more remarkable in view of the short period of daylight, the restriction on the penetration of the low

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Table 4

Averages of Temperature - Period 1931-60 and Extremes

Month	Stonehaven (12 ft)							Arbroath (95 ft)						
	Average			Extremes Ø				Average			Extremes Ø			
	Max	Min	Mean	Max	Year	Min	Year	Max	Min	Mean	Max	Year	Min	Year
	°C	°C	°C	°F		°F		°C	°C	°C	°F		°F	
Jan.	6.4	0.1	3.2	57	1932 '38 '44 '53	10	1958	5.8	0.2	3.0	57	1922 '32 '53	4	1941
Feb.	7.0	0.4	3.7	63	'43	16	'58	6.6	0.7	3.7	61	'27	12	'47
Mar.	8.7	1.6	5.2	68	'38	15	'47 '58	8.4	1.9	5.1	68	'29	9	'47
Apr.	11.3	2.8	7.1	70	'52	25	'54 '58	11.1	3.5	7.3	70	'14 '21 '46	19	'22
May	13.1	5.2	9.1	71	'39 '60	26	'42	13.4	5.6	9.5	80	'22	26	'15 '27
Jun.	16.2	8.1	12.1	83	'39 '50	32	'32	16.4	8.3	12.3	83	'39 '40	31	'36
Jul.	18.2	10.3	14.2	81	'58	38	'43 '58	18.2	10.5	14.3	86	'33	37	'22
Aug.	17.9	9.8	13.9	81	'59 '64	34	'56	17.8	10.3	14.1	82	'16	35	'46
Sep.	16.3	8.1	12.2	79	'33	27	'54	15.9	8.5	12.2	76	'29 '38	28	'42
Oct.	13.1	6.2	9.6	70	'31 '49	24	'48	12.5	6.0	9.3	72	'25	22	'26
Nov.	9.6	2.9	6.3	65	'38	18	'62	9.1	3.2	6.1	67	'33	16	'19
Dec.	7.5	1.3	4.4	59	'31 '41 '47	17	'64	6.9	1.7	4.3	58	'31	11	'47
Year	12.1	4.7	8.4	83	'39 '50	10	'58	11.8	5.0	8.4	86	'33	4	'41

Ø See Preface for explanation of use of °F

Table 4 (contd.)

Averages of Temperature - Period 1931-60 and Extremes

Month	Fettercairn (560 ft)							Balmoral Castle (927 ft)						
	Average			Extremes Ø				Average			Extremes Ø			
	Max	Min	Mean	Max	Year	Min	Year	Max	Min	Mean	Max	Year	Min	Year
	°C	°C	°C	°F		°F		°C	°C	°C	°F		°F	
Jan.	4.5	-1.1	1.7	56	1953	15	1952	3.9	-2.6	0.6	58	1927	-2	1963
Feb.	5.1	-0.7	2.2	56	'62	13	'63	4.5	-2.2	1.2	57	'38 '39 '53	-8	'55
Mar.	6.9	0.5	3.7	64	'53	21	'54	6.8	-0.9	3.0	69	'46	-3	'47
Apr.	10.0	2.2	6.1	65	'58	25	'50	9.7	1.1	5.4	75	'14	10	'17
May	12.8	4.6	8.7	69	'54	28	'51	13.4	3.3	8.3	78	'19	21	'14 '15 '27 '42
Jun.	15.9	7.4	11.7	81	'59	34	'52	16.5	6.4	11.5	88	'14	26	'36 '64
Jul.	17.7	9.3	13.5	80	'55	37	'49	17.9	8.5	13.2	85	'55	29	'19
Aug.	17.3	9.0	13.2	78	'55 '64	36	'64	17.3	7.9	12.6	85	'14 '55	28	'32
Sep.	15.1	7.3	11.2	77	'55	29	'54	14.8	6.1	10.5	76	'33	22	'42
Oct.	11.3	4.8	8.1	67	'49 '59	27	'55	10.8	3.5	7.2	75	'26	15	'26
Nov.	7.9	2.2	5.1	59	'64	23	'63	7.1	0.7	3.9	64	'46	-6	'19
Dec.	5.9	0.5	3.2	58	'56	16	'61	5.1	-0.9	2.1	56	'18 '31 '48	-3	'37
Year	10.9	3.8	7.3	81	'59	13	'63	10.7	2.6	6.6	88	'14	-8	'55

Ø See Preface for explanation of use of °F

Table 4 (contd.)

Average of Temperature - Period 1931-60 and Extremes

Month	Montrose Hospital ‡ (186 ft)							Glamis Castle ‡ (200 ft)						
	Average			Extremes Ø				Average			Extremes Ø			
	Max	Min	Mean	Max	Year	Min	Year	Max	Min	Mean	Max	Year	Min	Year
	°C	°C	°C	°F		°F		°C	°C	°C	°F		°F	
Jan.	5.1	-0.4	2.3	55	1957	14	1955	4.4	-2.2	1.2	57	1957	2	1963
Feb.	6.2	0.1	3.1	56	'62	13	'56	5.6	-1.6	2.0	54	'58 '61 '62	7	'58
Mar.	8.2	1.4	4.8	67	'65	12	'65	7.6	0.0	3.8	67	'65	3	'58
Apr.	11.4	3.1	7.3	67	'58	26	'61	11.1	1.7	6.4	66	'58	20	'61
May	13.7	5.3	9.8	70	'54 '65	31	'57	13.8	3.9	8.8	74	'56	26	'57
Jun.	16.9	8.1	12.5	76	'62*	36	'62	17.0	7.1	12.1	80	'59	31	'64 '65
Jul.	18.4	10.1	14.3	81	'55	38	'55	18.7	9.1	13.9	78	'58	33	'62
Aug.	17.9	9.4	13.6	78	'59	36	'64	18.2	8.8	13.5	79	'61	31	'64
Sep.	16.2	8.1	12.2	77	'55	32	'54	16.1	6.3	11.2	77	'59	29	'57
Oct.	12.3	5.5	8.9	66	'55	28	'55	12.8	3.9	8.1	70	'59	25	'56
Nov.	8.5	2.4	5.4	57	'64	22	'62	8.1	0.8	4.5	58	'64	16	'65
Dec.	6.1	0.9	3.8	56	'64	19	'61 '64	5.7	-0.7	2.5	55	'56	13	'61 '62
Year	11.8	4.5	8.2	81	'55	12	'65	11.4	3.1	7.3	80	'59	2	'63

‡ Computed Averages (Provisional) Ø See Preface for explanation of use of °F

* Not Available for June 1959

Extreme values for periods:-

Stonehaven	1930-64
Arbroath	1914-46; 1951-64
Fettercairn	1949-64
Balmoral Castle	1914-64
Montrose Hospital	1954-65
Glamis Castle	May 1956-Dec. 1965

angled winter sunshine into the glen often imposed by the topography, and because it occurs even when there is general snow cover. Thus at Strachan (395 ft) and Whitehillocks (845 ft), stations only recently established, a daily range in winter of 20°F (11°C) proves to be not unusual, one of 25°F (14°C) relatively frequent and a range of 30°F (17°C) or more has already been noted.

"Freezing Days"

A mean minimum temperature of 0°C or below for any month implies a fair frequency of frosty nights during that month. An assessment of the severity of the season may also be obtained from the number of days sometimes called "Freezing Days", on which the arithmetic mean of the maximum and minimum temperatures for the day does not exceed 0.2°C. A probable average for much of the Vale of Strathmore (based on the Fettercairn data) is some 28 to 30 such days per winter season, with 9 to 10 days each in January and February. The year to year variation is however considerable - from 6 to 10 days in a mild winter to some 55 to 60 days in a severe one.

Sunshine

Sunshine is one of the major meteorological elements necessary in the assessment of climate, and to the Lowlands and foothills of east Scotland falls the distinction of being on average the sunniest part of the Scottish mainland. The mean annual isohel for 1300 hours follows reasonably closely the major conformation of the 750 ft contour, and thus runs southwest to northeast across the centre of the areas under review, before turning toward northwest across the Dee Valley. Average sunshine figures for the year increase steadily southeastwards from this line to 1500 hours in the vicinity of Arbroath, and decrease, but more rapidly, to northwestwards of it (Table 5).

Table 5 Average of Sunshine (Hours) - Period 1931-60

	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Arbroath	56	86	115	166	198	200	180	157	139	102	63	43	1505
Montrose	53	81	102	154	177	181	159	143	129	94	59	43	1375
Stonehaven	52	76	101	147	175	179	154	141	124	91	57	41	1338
Fettercairn*	54	78	106	144	178	168	148	139	115	82	56	43	1311

* Computed Averages

Spring is normally the most consistently sunny period of the year, with May the sunniest month on the whole, although June is almost as sunny in coastal districts. In spring the high ground enjoys on average only about half an hour per day less than the Arbroath area, or only some 45 to 50 hours less over the season. In summer this relatively small range of half an hour per day extends from the coast only to the lower foothills, due largely to the considerable increase in cloudiness inland in August, whilst with the onset of the autumn rains the difference increases to over one hour per day, to the detriment of the higher levels. Bright, if crisp, days in winter raise the average sunshine figures to levels comparable with, and sometimes in excess of, those for similar rural situations in the southern half of England in spite of the much shorter day in Scotland. The Sidlaw hills and the more westerly section of the Vale of Strathmore also reflect proportionately the high values of the Arbroath district.

This favourable sunshine distribution can be at least partly attributed to föhn (lee slope) winds breaking or even clearing the cloud. It should be remembered however, that the official sunshine records relate to completely unobstructed sites, and that in the foothill glens in particular, the obstruction of sunshine by the slopes can very substantially reduce the sunshine received on local sites.

/ Föhn

Föhn and Haar

Winds from the west to northwest sector and from the east to northeast sector have each been shown to have a marked seasonal incidence. Each tends to bring characteristic day to day weather when it prevails and so makes an impress on the general overall climate of the region.

Föhn

Föhn conditions are frequently associated with the westerly winds and are almost entirely beneficial. The degree of development depends on the prevailing pressure distribution and that which produces a broad belt of strong westerly winds (in the free atmosphere) is the most effective. The air stream, already denuded of a fair proportion of its moisture, spills over the final ridge of the mountain barrier and loses much of its momentum as it descends to the valley floors and the lowland plains. In its descent the air is warmed by adiabatic compression and the relative humidity consequently falls; the lower cloud sheets break up and often disappear and at least a partial clearance of the medium cloud forms often results. The extra bonus of sunshine by day helps to raise the temperature and brings a further decrease in relative humidity, although at night the clear skies encourage radiative cooling. Even moderately well developed föhn extends to the coast, and the onset is marked by the sharp rise in temperature and fall in relative humidity which accompanies the veer of the wind to west or beyond. In the Dee valley the effective wind direction for föhn is more noticeably the southwest to west sector. Southwestward of the Finhaven-Aberlemno hills (Forfar area) the phenomenon is probably rather less decisive, requiring a more northwesterly airstream for maximum development. Föhn may last for a few hours or, in varying degree, for up to two days or so. It occurs at all seasons, but the effects are perhaps more obvious in autumn and in winter. It can be a powerful agent for snow clearance. Westward, toward the foothills, especially in Angus, some retardation in the development of the crops as compared with those further east (presumably in later spring) is attributed to "the cold wind off the mountains". Obviously föhn winds are being blamed rightly but for the wrong reason. The real culprit is not so much the air temperature (which is higher than it would have been without the föhn) but the low humidity which engenders a high rate of evapotranspiration inducing an increased feeling of cold in the human and placing a stress of moisture deprivation on growing vegetation.

Haar

Haar is the bugbear of easterly winds, invariably bringing a penetrating damp rawness. The term has come to be used loosely and is often applied not only to the cold wet sea fogs of spring and summer but also to the very low clouds sometimes coming inland on the southeast winds ahead of depressions at other seasons.

True Haar is a phenomenon mainly of the spring and early summer, with fog or very low cloud occurring with what is otherwise a fine weather situation. Intrinsically warm air from the continent, drifting over the cold North Sea absorbs moisture whilst being cooled to near the sea surface temperature. The surface air is saturated or nearly so when, with the easterly winds, it approaches the Scottish coast. If fog or very low cloud has not already formed, the slight lift over the coast and the evening fall of temperature complete the process and fog spreads relentlessly inland, although occasionally the uplift at the foothills may be necessary for the final condensation in which case the fog builds back coastwards. Sometimes the vertical thickness of the fog is such that the sun is unable to penetrate and fog persists over appreciable areas for perhaps two or three days. More frequently the sun breaks through well inland and the fog is then often made to retreat towards the coast, only to advance again as the temperature falls off later in the day. The process may be repeated at varying intensities for several days on end. This form of haar is however very sensitive to wind direction, and the edge of the fog zone is often very sharply delineated. Fog will come in quickly over the coast on the sea breeze to advance less quickly inland and it is probably true to say that the real haar occurs more frequently in the lowlands than in the foothills. Certainly a ridge of higher ground is an effective barrier against further penetration to leeward.

/ In

In its other manifestation, although the same causative factors operate to a certain extent, an advancing frontal system causing southeast to east winds ahead of it, is involved. Effectively a layer of very low cloud develops, at some 200 ft to 500 ft above sea level enveloping the foothills and any areas of raised ground and with very poor visiblity at the lowest levels. It is soon accompanied by a period, often prolonged, of cold rain or drizzle. The majority of really wet days giving, say, half an inch of rain or more over a considerable area of the lowlands and hills are of this type.

Humidity

Reference has been made in the preceding section to the occurrence of low humidities. Some interesting detail derives from analysis of six years of detailed observations at Montrose airfield and reveals some climatic aspects which are largely obscured by the more usual monthly averages of relative humidity at two or three stated hours during the day, even when these are available.

Table 6 shows the percentage frequency of occurrence of relative humidities within the stated limits as distributed through the working day during the various "growth periods" of the year. The "seasonal" grouping is facilitated by the fact that the distribution in the various ranges is reasonably similar for each of the months contained within each group. "Forenoon" relates to observations at 07 and 10h. GMT, "afternoon" to those for 13h. and 16h. GMT and "evening" to 18h. GMT. The increased frequency of higher humidities from July to September compared with April to June is in part associated with the normal increase in rainfall at that season. Occurrences of humidities below 60%, are of interest as being rather unusual in our sea-girt islands. Their frequency is considerable from March to September though understandably greatest in the normally dry period of spring and early summer. But low humidities can occur at all times of the day even in the winter period. In most cases their occurrence is conclusive evidence of well developed föhn although there are many cases of föhn when the relative humidity drops sharply some 20% or more from the higher ranges without falling to the lowest ones.

It is almost certain that low to very low humidities occur more frequently and probably persist longer than the tabulation suggests in some districts well inland and in the foothills. The original data clearly show the ease with which the sea breeze develops in the Montrose basin area in quiet fine weather in the warmer part of the year. The sea breeze brings in additional moisture in the lower layers and the relative humidity rises sharply, the higher humidity moving inland with the breeze. A penetration inland of some 10 miles or so (i.e. to the foothills) is likely with a well developed sea breeze, but the penetration takes time and the humidity change is stopped or reversed sooner the further inland it reaches as the breeze weakens.

It has now been firmly established (3)(4) that exceptionally low relative humidities occur, at least in the more northerly section of the foothills. Minimum values below 10% for short periods and values below 20% persisting for several hours have been measured at Strachan with rather similar figures at Whitehillocks on an occasion when the humidity was generally below 40% over a fairly wide area of Kincardineshire and Aberdeenshire.

Growing Season

The meteorological parameters which have been discussed all have a place in the complicated pattern of vegetative growth and enough is now known to enable data for some of the elements to be used to give definite pointers to the rate of growth and the periods during which growth may be sustained. Thus the availability or otherwise of the necessary soil moisture can be indicated by offsetting the incidence and amount of the rainfall against the evapotranspiration. Penman utilises mean values of wind speed,

/ temperature

Table 6 Relative Humidity - Montrose (Airfield) 1940-44

Percentage Frequency of Occurrence of Humidities in Various Ranges

Rel. Hum. %		100-90		80-89	70-79	60-69	50-59	40-49	30-39
		96-100	90-95						
Dormant Season	Nov. and Feb.								
	Forenoon	15.2	28.8	35.9	15.9	3.8	0.4	-	-
	Afternoon	9.9	17.9	31.9	25.5	12.1	2.4	0.3	-
	Early Evening	14.4	25.3	33.4	20.4	5.1	1.2	0.2	-
Transition Months	Mar. and Oct.								
	Forenoon	17.9	20.2	33.6	17.3	10.2	0.8	-	-
	Afternoon	7.3	11.6	27.8	21.0	19.2	11.5	1.6	0.1
	Early Evening	11.3	23.6	27.8	23.9	9.4	3.9	-	-
Growing Season	Apr.-Jun.								
	Forenoon	9.1	12.0	28.7	23.8	17.5	7.7	1.1	0.1
	Afternoon	5.3	10.9	19.7	24.0	18.4	15.3	5.5	0.9
	Early Evening	6.6	13.4	25.8	24.4	17.4	9.3	3.1	-
Ripening Season	Jul.-Sep.								
	Forenoon	13.8	16.9	29.2	23.5	12.0	4.3	0.4	-
	Afternoon	5.0	9.2	23.0	23.0	22.6	14.1	2.9	0.3
	Early Evening	7.9	13.4	29.8	25.0	17.1	6.3	0.4	-

temperature, sunshine and vapour pressure to derive the average evapotranspiration (P.T.) from a grass covered surface assuming that ample moisture is available to the roots. The latest assessments are given in M.A.A.F. Bulletin No. 138 - "Irrigation" and those for Angus and Kincardineshire are reproduced here.

Average Values of Potential Evapo-transpiration

	Apr.	May	Jun.	Jul.	Aug.	Sep.	Apr.-Sep.	Oct.-Mar.	Year
Inches	1.75	2.65	3.10	2.95	2.50	1.25	14.20	2.45	16.65

Comparison with the average rainfall figures suggests that, in general, over-dry soil conditions occur only infrequently in the foothills and over much of the lowlands. The period of greatest risk is that from mid-May to mid-July especially on the lighter soils and in the coastal zone.

The duration of the growing season, on the basis of a threshold mean daily temperature of 42°F (6°C) is greatest in the coastal zone with an average length of from 235 days in the north to 245 days in the south, from approximately the last week in March to the third week of November. At the approach to the foothills the season normally begins nearly three weeks later and ends about a fortnight earlier and a total of around 225 days is probably valid for the Forfar area and the lower Dee valley. The reduction with altitude into the foothills reduces the total to just below 200 days at 1000 ft.

Some indication of the average growth rates is given by the "Accumulated Temperatures" in Table 7. (The Accumulated Temperature is a summation of the periods of time during which the temperature exceeds the threshold of 42°F (5.6°C) expressed in "degree days" and average values are conveniently calculated from average monthly temperatures by a method due to Shellard[5]). The general pattern over the whole year is a maximum of well over 2500 degree-days in the south coastal zone decreasing to rather more than 2400 near the coast in the extreme north. The totals decrease to the northwestwards, at first relatively slowly across the lowlands and then more rapidly with increasing altitude from around 2200 degree-days at 500 ft to less than 2000 at around 1000 ft.

Table 7 Average "Accumulated Temperatures" above 42°F (5.6°C) - in "degree-days"

(Period 1931-60)

Location	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
Arbroath	37	51	96	126	220	363	487	477	360	211	78	53	2559
Glensaugh	25	29	68	89	182	330	443	425	303	152	51	34	2131
Balmoral	25	25	62	63	164	318	425	394	264	127	31	31	1929

Soil temperature also contributes to the growth cycle, but little is known about the actual variation from place to place with the type and texture of the soil in this area. Most observations available refer to 09h. GMT under bare soil. For most practical purposes, these readings at a depth of 4in. can be assumed to be an approximation to the mean value for the day at that depth in summer when the diurnal variation there can be at least as much as 6°C especially with dry, bare soil in sunshine. The corresponding readings at the 8in. depth are not greatly different from the minimum value for the day at that depth in summer. A period of rain tends generally to equalise temperature at the two levels. As a guide, mean monthly values for Fettercairn are given below for depths of 4in. and 8in.

/ Table 8

Table 8 Monthly Mean Soil Temperatures °C at 09h. GMT - Fettercairn (1951-64)

Soil Depth	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.	Year
4 in.	0.7	0.9	2.4	4.9	8.8	12.1	13.7	13.0	10.8	7.8	4.4	2.1	6.8
8 in.	1.2	1.4	2.8	5.1	8.7	11.8	13.7	13.2	11.3	8.4	5.2	2.7	7.1

It is perhaps appropriate to re-capitulate some of the advantages (and disadvantages) accruing to the region as suggested by the detailed examination of the various climatic factors already discussed. The relative freedom from strong to gale winds, resulting from the mountain shelter, has the obvious practical advantage of minimising mechanical damage to the growing vegetation, and does to some extent reduce the potential evapotranspiration. In winter however this reduction in wind speeds increases the incidence of severe frost. The tendency to showery weather in May mitigates the risk of vegetative stress due to moisture shortage in what is otherwise a rather prolonged dry season, but the attendant low temperatures tend to slow down or check growth. The haars of later spring and early summer although they provide moisture which may sometimes be welcome also slow down growth and in varying degree cut down the insolation. This latter situation is however more than retrieved by the beneficient föhn particularly in autumn; föhn also contributes to the substantial winter sunshine. Above all, the frequency of föhn conditions is such that the accompanying higher temperatures undoubtedly leave their impress on the monthly means of maximum temperature, and help to prolong the growing season well into the autumn. Since the summer rainfall is normally more than adequate, the low humidities invariably associated with föhn rarely raise the evapotranspiration to levels which the vegetation cannot sustain without damage. On the other hand it does dry off the foliage rapidly after rain and also quickly dries out the surface layer of the soil with its obvious gain in practical husbandry.

Hail, Thunder and Fog

This memorandum would be imcomplete without some reference to what may be referred to as "day-to-day" phenomena, the frequencies of which are shown in Table 9.

Hail may occur in most months, but is least likely in autumn. The showery north to northeasterly weather of May is most likely to bring hail stones of the damaging type. The relatively high average figures for the winter months and those for at least the early spring months include an unknown proportion of cases of "soft" hail or granular snow.

The distinctly low frequency of hail in the thunder period of the year is interesting since hail and thunder often occur together. This anomaly appears to be peculiar to parts of Scotland, especially the eastern side. Thunder is on the whole most commonly recorded in July but both June and August can be thundery. The storms normally develop over the higher ground, probably as a result of heated pockets of air being trapped in the glens and valleys, and then drift over the lower ground to degenerate into rather extensive rain areas. Thunder is extremely rare toward the turn of the year and in the opening months, and any storms at this season are almost invariably confined to the coast.

Fog, of the shallow "radiation" type during quiet weather is not very frequent but it tends to develop over the lowest ground when skies clear following the thundery rains of late summer. In the absence of industrial pollution, fog is mainly quite local and clears quickly in situ during the early forenoon. "Haar" fogs, as have already been described, affect considerable areas in spring and early summer and can be very persistent near the coast. Very low cloud often envelops the foothills, especially on their eastern side during the wetter season of late autumn and early winter as is reflected in the high average of 34 mornings of fog per annum at Fettercairn.

/ The

Table 9 Climatological Summaries

Average Number of Days of Occurrence of Specified Phenomena - Period as Shown

(For explanation of headings and notes on air frost and ground frost data see Preface)

	95 ft. ARBROATH - 1914-64 (51 yrs)						560 ft. FETTERCAIRN - 1948-64 (14-17 yrs)					
	H	T	F	AF	GF	G	H	T	F	AF	GF	G
Jan.	0.6	0+	1.7	13.9	17.7	1.3	1.3	0	3.2	19.3	24.7	2.7
Feb.	0.6	0	1.9	11.8	15.8	1.0	1.0	0	2.8	17.9	21.9	1.5
Mar.	0.6	0+	2.1	4.2	13.6	0.9	0.5	0	4.9	8.3	17.3	0.7
Apr.	0.9	0.2	0.9	1.8	9.9	0.6	1.1	0+	2.6	5.7	16.5	0.5
May	0.7	0.8	1.3	0.1	4.9	0.1	1.3	1.0	1.9	1.1	8.7	1.3
Jun.	0.2	0.7	0.7	0	1.2	0.2	0.2	0.5	1.1	0	2.0	0.7
Jul.	0+	1.7	0.9	0	0+	0+	0.2	1.2	1.9	0	0.6	0.8
Aug.	0.1	1.3	1.0	0	0.3	0.2	0.3	1.0	2.1	0	1.4	0.6
Sep.	0+	0.5	1.0	0	2.7	0.5	0+	0.3	3.4	0	3.7	0.7
Oct.	0.1	0.2	1.3	0.1	6.1	0.9	0.3	0+	3.1	1.3	10.5	1.1
Nov.	0.4	0.1	1.7	4.4	12.6	1.0	0+	0	3.4	7.4	18.3	0.6
Dec.	0.6	0+	1.6	10.3	16.5	1.1	1.0	0	3.3	16.6	24.5	1.1
Year	4.8	5.5	16.1	46.6	101	7.8	7.2	4.0	33.7	78	150	12.3

	MONTROSE (LINKS) - 1916-53 (34-38 yrs)				927 ft. BALMORAL - 1914-49/1956-64 (43-44 yrs)			
	H	T	F	G	H	T	AF*	GF
Jan.	0.7	0.1	0.6	1.2	VERY INFREQUENT	0+	23.3	22.7
Feb.	0.8	0.1	0.6	0.9		0+	21.6	20.3
Mar.	0.6	0+	1.1	0.7		0	15.0	20.4
Apr.	0.9	0.3	0.7	0.7		0.2	11.9	15.2
May	0.6	0.8	1.1	0.5		0.7	5.3	9.6
Jun.	0.3	0.9	0.3	0.2		0.8	1.1	3.1
Jul.	0.1	1.3	0.5	0.1		1.3	0.3	0.8
Aug.	0	0.9	0.7	0.1		0.9	0.6	1.3
Sep.	0.1	0.4	0.7	0.2		0.2	2.1	4.6
Oct.	0.1	0.3	0.9	0.6		0.1	4.2	10.3
Nov.	0.5	0.1	0.9	0.9		0.1	14.1	16.9
Dec.	0.7	0+	0.5	1.1		0.1	19.1	21.0
Year	5.4	5.2	8.6	7.2	0.9	4.4	119	146

Notes: 0+ denotes < .05

* 1956-1964 only

/ Table 9 (cont.)

Table 9 (contd.) Climatological Summaries

	200 ft. GLAMIS CASTLE - May 1956-64 (8-9 yrs)						80 ft. BALMAKEWAN† - 1930-36 (7 yrs)				
	H	T	F	AF	GF	G	H	T	F	GF	G
Jan.	0	0	0.9	20.5	26.3	0.9	0.1	0	1.2	22	0.7
Feb.	0	0	2.4	17.2	21.1	1.5	0	0	0.8	21	0.5
Mar.	0.3	0	2.0	10.1	14.0	0.5	0.3	0	2.4	20	0.6
Apr.	0.4	0.9	0.4	7.1	14.0	0.5	0.6	0.1	0.6	15	0.9
May	1.2	1.7	0.3	1.8	-	0.4	0.4	0.4	0.1	8	0.1
Jun.	0.8	1.8	0.7	0.1	-	0.6	0	1.1	0.3	1	0
Jul.	0.1	1.6	0.3	0	-	0.3	0	1.9	0.6	0	0.1
Aug.	0.1	1.7	0.5	0.2	-	0.9	0.2	1.2	0	0+	0.2
Sep.	0	0.8	2.2	0.7	-	0.9	0	0.3	1.0	3	0.2
Oct.	0.1	0.1	1.8	2.7	-	1.0	0	0.5	0.2	13	1.0
Nov.	0.2	0.1	1.9	12.0	19.9	0.8	0	0	0	21	0.5
Dec.	0.3	0	2.3	19.5	24.0	1.4	0.2	0	1.8	18	0.8
Year	3.5	8.7	15.7	92	-	9.7	1.8	5.5	9.0	142	5.6

	210 ft. MUCHALLS - 1950-64 (14-15 yrs)				
	H	T	F	AF	GF
Jan.			0.3	14.1	22.2
Feb.	V	V	0.8	12.7	19.0
Mar.	E	E	1.8	5.2	14.6
Apr.	R	R	0.9	3.2	12.8
May	Y	Y	1.8	0.7	5.9
Jun.	I	I	1.5	0	0.6
Jul.	N	N	1.6	0	0+
Aug.	F	F	1.2	0	0.1
Sep.	R	R	0.9	0	0.8
Oct.	E	E	0.5	0.2	4.8
Nov.	Q	Q	0.6	3.6	12.2
Dec.	U	U	0.2	10.3	20.5
Year	E	E	12.1	50	113
	N	N			
	T	T			
	1.1	1.6			

† mild winter of 1930's

The Climate of the Mountain Area

Discussion in the earlier sections has been confined to the lowlands and foothills, in which with some observational data, however limited, up to 1,100 ft, it has been possible to outline the climatic deterioration with altitude up to about 1,500 ft.

To complete the picture of a further change to a near alpine climate as one ascends the higher hills into the near mountain terrain where local observations are almost completely lacking, reasoned assessment only is possible using various snippets of information that are available on high altitude conditions (e.g. G. Manley[6]). It is perhaps stating the obvious to remark on the cool summer and the short growing season at about 2,000 ft and above, or on the persistence of frost in winter and the accumulations of snow in some, if not all, winters at these levels.

Winds, which at these altitudes conform more closely to those of the free atmosphere have a mean value over a quiet month probably of about 15-16 kt. (18 mph) increasing to 20 kts. (23 mph) or above in moderately disturbed months. Near surface winds round exposed peaks, ridges etc. especially when they lie across the prevailing southwest to west winds frequently exceed the speeds in the free air, and probably do so in "funnels" lying along the line of the wind between peaks, whereas on the sheltered lee side of higher masses, speeds are very considerably lower. In most months it is not unusual to have a period in which a sustained wind of around gale force (33 kt., 38 mph) persists for a day or more over an exposed area. At the climax of a severe storm a sustained speed of 75 kt. (86 mph) or more is more than likely. Around the peaks gust speeds in excess of 100 kt. (115 mph) are probably not rare.

Fig. 2 shows that the average annual rainfall is estimated to be about 50 in. at 1,500 ft. increasing to some 60 in. or more at the highest levels. This total is considerably below those on the "oceanic" side of the Scottish mainland because of the shelter provided by the extensive mountain masses to the west. The drier period from February to June has on average about one third of the annual rainfall, March and June being the driest months. October and November have the highest monthly averages, slightly in excess of those for December and January; in next place are July and August. Of the annual precipitation some 20% probably falls in the solid form at around 2,500 ft. with a decrease towards lower altitudes. A considerable amount of snow is blown off the highest peaks by the high winds and deposited at lower levels in more sheltered zones. The average number of days of snow lying on a reasonably level and not over-exposed area is of the order of some 100 to 110 days per year above 2,000 ft, but the number is increased by one-third or more for considerable areas prone to accumulate drifts.

The mean monthly temperature at altitude may be assessed, very approximately, by a reduction of 3°F per 1,000 ft. in the long period averages of a suitably located lower level station, but the little evidence available (from recent observations in the Cairngorms) suggests that actual mean monthly values do not conform very closely to this rule. Mean monthly maximum temperatures are appreciably lower than the calculated values, particularly in spring when bursts of polar air bring very low temperatures at altitude compared with those in the valleys. The threshold of 42°F (5.6°C) for the commencement of the growing season may not be attained until well into May. Differences between minima are much less marked between different altitude levels, since on clear calm nights the surface air at the higher levels, on cooling, drains down the slopes to accumulate in the valley bottoms. The resultant airflow down the hill/mountain sides (the katabatic wind) is a recognised feature of the climate of these areas of broken topography in fine, quiet spells. Because of this phenomenon there arises the interesting anomaly that the first night frost of the autumn at altitude occurs considerably later than the earliest frosts in the adjacent valleys, whilst on very cold nights the valley bottom is often colder than it is at the higher levels.

July seems to be the warmest month and in most years the temperature at the highest levels can be expected to reach 18°C to 19°C on the warmest days.

/ Absolute

Absolute maxima exceeding 70°F (21°C) occur in some years at 2,500 ft. Through the harsh winter the daily mean temperature at around 2,500 ft. from November to February is mostly at or below freezing point or below with mean minimum temperatures well below that level. March and early April can be equally cold. February is probably the coldest month, since January, affected more frequently by Atlantic depressions, is apt to have periods of "milder", cloudy and wet weather when the diurnal temperature variation is almost negligible. Warmer weather at altitude than down in the valleys is not altogether rare and the temperature difference may sometimes be around 6°C or more. This occurs during quiet anticyclonic weather, usually in the colder part of the year when the subsidence inversion above the surface frosty layer falls to about 2,000 ft. ASL or lower.

The occurrence of very low humidities at less elevated levels have been referred to in an earlier section. Exceptionally low relative humidities were measured at the famous observatory on Ben Nevis (4,406 ft) towards the end of the last century, but it seems doubtful whether these occur at levels of say around 2,000 ft. on the "oceanic" side of Scotland. Recently however it has been established that exceptionally low values, 10% or below, occur occasionally at the levels of the higher ground within the region under review, chiefly in autumn and early winter.[3 & 4] The three factors involved, in order or priority are:- high level subsidence, föhn effect, and less importantly, the diurnal temperature variation on a fine quiet day. The indications are that these exceptional values are confined to levels above about 2,000 ft. and usually persist for a few hours. Frequently they are more or less synchronous with very low values (20 to 30%) down to levels of 1,000 ft, and sometimes, though not necessarily, with low humidity (below 50%) over appreciable areas of the lowest terrain. In contrast, of course, are those days of all pervading wetness due to envelopment in cloud and especially those when, with sub-freezing temperatures, practically everything becomes encased in a thick covering of rime ice.

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