Climatic studies in North East England

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CLIMATIC STUDIES IN NORTH EAST ENGLAND

by

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ABSTRACT

This thesis applies a two-dimensional analysis to three problems. Each problem utilizes the daily observations of sunshine duration and maximum temperature recorded at Durham Observatory from July 1937 to June 1962.

The analysis is termed 'two-dimensional' since it classifies meteorological data according to time of year and mean daily wind direction. This procedure was initially devised to describe, in Part 1, the effects of a local climatic phenomenon which is associated with wind from a particular direction. Parts 2 and 3 apply the two-dimensional analysis to problems of zonal interest.

Part 1 describes the effects of the haar upon daily sunshine duration and maximum temperature. It observes that these effects are unexpectedly weak but it stresses that this observation may be caused by a general failure of two-dimensional analyses to detect rare, intermittent phenomena such as the haar.

The second part of the thesis describes and explains the variations of daily sunshine duration which are detected by the two-dimensional analysis. These variations form the basis of a three-fold subdivision of 'rates of sunshine production' within air masses.

Part 3 correlates corresponding daily sunshine durations and maximum temperatures on a monthly basis. It observes a two-fold subdivision of the year. The summer period, including the seven months from March to September, is characterised by positive correlations which are pronounced on days with winds from the continent and weak on days with south west winds. The elements are usually uncorrelated in winter (the remainder of the year) but on days with south west and west winds in January they are negatively correlated. These observations are explained in terms of the seasonal changes in the relative magnitude of the components of the radiation balance.

The conclusion discusses the general applicability of the two-dimensional analysis within air mass climatology. It considers that this applicability is severely restricted by the complexity of air mass movement.

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INTRODUCTION

Each of the three parts of this thesis is based upon an analysis of the daily observations of sunshine duration and maximum temperature recorded at Durham Observatory between July 1937 and June 1962. The first part examines a local climatic phenomenon and the remaining parts discuss problems of zonal interest. The conclusion discusses the general applicability of the analysis which is the basis of this thesis.

A. THE ANALYSIS

The analysis classifies meteorological data according to time of year and 'mean daily wind direction'. It describes the mean properties of days with a particular wind direction in each month.

This procedure was devised for the specific purpose of detecting the effects of the haar upon daily maximum temperature and daily sunshine duration at Durham Observatory. Occurrences of the haar are selective with respect to time of year and wind direction. It is associated with onshore winds along the North Sea coast and it mainly occurs in late spring and early summer.

During this examination of the effects of the haar it appears that the analysis may have wider application within air mass climatology. The mean properties of days with particular wind directions vary considerably. It is suggested that these variations are functions of air mass properties and that the mean properties of days with a particular wind direction are controlled by the characteristics of the air mass which commonly invades the British Isles from that direction. The supposition that valid deductions concerning the mean properties of air masses may be derived from this analysis is tested in Parts 2 and 3. These parts apply the analysis to problems of zonal interest.

However, the association between daily wind direction and air mass type is weak. The conclusion examines a number of causes of this weakness. These include the contrast between geostrophic and surface wind directions, the effects of the curvature of the trajectory of an air mass upon its properties and the arrival of unlike air masses from similar directions. The thesis concludes that the useful applications of the analysis are within local climatology and that its rôle in air mass climatology is merely descriptive.

B. PART 1

Visitors to north east England occasionally commend the bracing quality of the weather and Hawkins[1] shared their opinion when he estimated that the North Sea coast between Berwick and the Wash is the only part of England and Wales having a 'very bracing' climate. Although vague, these terms emphasise the observation that in summer onshore winds along this coast suffer marked advection cooling.

Rather more precise are the remarks of a farmer in east Durham who complained that 'we come to harvest about three weeks later than the Catterick area, or a fortnight later than the Tyne valley'. This delay is possibly an indirect result of the advection cooling of onshore winds. Occasionally this cooling is sufficiently pronounced to form decks of stratus cloud which, drifting inland, eliminate sunshine on otherwise fine, sunny days.

This peculiarity of the weather along the North Sea coast is recognised by the local inhabitants and names such as 'haar' in Scotland, 'sea-fret' or 'sea-pine' in Northumberland and Durham, and 'north-roak' in Yorkshire testify to this recognition.

Part 1 describes some effects of the haar upon the climate of Durham city. The form of this analysis evolves from two basic observations concerning the effects and occurrence of the haar.

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[1] HAWKINS, E., Medical climatology of England and Wales. London, (Lewis), 1923

The effects of the haar are complex but of primary importance are its reductions of daytime temperature and sunshine duration. The daily records of maximum temperature and sunshine duration are therefore the basis of the analysis.

The occurrence of the haar is highly selective with respect to time of year and daily wind direction. Consequently, the analyses of the daily maximum temperature and sunshine duration records differentiate these elements according to time of year and wind direction. In both cases the data are classified into 96 groups each referring to a calendar month and one of eight wind directions. Frequency distributions derived from this classification are the basis of the analysis.

Part 1 commences with a general discussion of the causes and effects of the haar. Chapters 3, 4 and 5 describe the records of maximum temperature and sunshine duration, emphasising those features of these records which may be attributed to the haar. Surprisingly few such features are detected and Chapter 6 establishes that this may have resulted from inadequacies in the form of the analysis.

C. PART 2

Part 1 classifies the daily observations of sunshine duration into 96 groups. Naturally there are wide variations in the properties of the frequency distributions derived from this classification. The main variations are two-fold. The simplest variations are caused by seasonal changes in the duration of daylight. Additionally there are variations, in each month, among the frequency distributions distinguished according to daily wind direction.

Part 2 emphasises and explains the latter variations. The emphasis is achieved by expressing all durations as percentages of the possible duration. This eliminates the effects of seasonal changes in the length of daylight. The resultant 'adjusted frequency distributions' vary widely according to wind direction in each month.

A generalised description of these adjusted frequency distributions indicates that sunshine durations may be classified into three categories on the basis of their variations according to wind direction and time of year. Chapter 7 outlines the variations in the frequencies of these 'low', 'medium' and 'high' sunshine amounts and this information is used, in Chapter 8, to describe the frequencies of different 'rates of sunshine production' in air masses. Chapter 9 discusses these variations and attributes them primarily to seasonal changes in the intensity of solar radiation, orographic uplift and subsidence in the atmosphere, and the stability and vapour pressure properties of air masses.

D. PART 3

The relationships between corresponding daily observations of sunshine duration and maximum temperature are described and explained in Part 3. Coefficients of correlation between these elements are calculated and these are differentiated according to time of year and wind direction.

The variations of these coefficients are described in Chapter 10. Although these variations are two-fold their seasonal component greatly predominates over the component determined by daily wind direction. Positive correlations predominate in summer (March to September) and the data are generally uncorrelated in winter (October to February). The transi~~a~~tions between these periods are abrupt. The effects of wind direction upon this correlation are interesting since the summer positive correlations are strong on days with winds from the continent and weak on days with south west winds. In January the data are negatively correlated on days with south west and west winds.

In Chapter 11 these observations are explained in terms of the seasonal changes in the relative magnitude of downward short wave and upward long wave radiation.

PART 1

THE HAAR

CHAPTER 1

CAUSES AND EFFECTS OF THE HAAR

This introductory chapter commences with a general outline of the weather effects and the distribution of the haar. Both the regional and the seasonal distributions are outlined.

Following this are more comprehensive studies of its causes and its climatic effects. The former examines oceanographical, meteorological and topographical factors separately. The latter describes the effects of the haar upon fog frequency, cloud frequency, sunshine distribution and temperature along the east coast of Great Britain.

Despite a considerable number of oblique references to the haar within discussions of coastal fog, stratus cloud and sunshine conditions few papers are specifically concerned with the phenomenon. Manley[1] first drew attention to the haar with an account of personal observations made during his residence in Durham city. Lamb[2] collected short-term information (1937 to 1938) from a large number of coastal stations in order to emphasise the relevance of

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1. MANLEY, G., Some notes on the climate of north-east England. Quart.J.R.met.Soc., 61, 405, 1935.
2. LAMB, H.H., Haars or North Sea fogs on the coast of Great Britain. London, 1943

the haar to aviation.

A. GENERAL FEATURES

The haar is created by the advective cooling of relatively warm air masses passing westwards over the North Sea and the varieties of forms in which it occurs depend mainly upon the intensity of this cooling.

Surface fog is often produced by relatively intense cooling which causes condensation at the surface and which prevents the extensive uplift of moisture by stabilising these lower layers (Findlater[1]). Except in winter, the fog is mainly restricted to narrow coastal belts of the order of a half to one mile inland and a similar distance offshore. In spring and summer it is not unusual for the beaches and piers of the coastal resorts to be fog-bound throughout the day while warm, sunny conditions prevail in their town centres or inner suburbs. On some occasions of very high absolute humidity and low wind speed, the fog first appears along the shoreline. In these cases the air is first cooled to saturation by the adiabatic uplift due to the elevation of the land surface or to horizontal convergence arising from the relatively

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[1] FINDLATER, J., Thermal structure in the lower layers of anticyclones. <u>Quart.J.R.met.Soc</u>. 87, 513, 1961.

high friction over land surfaces (Lamb[1]).

Low stratus covers are associated either with less intense cooling and less stable surface layers, or with the subsequent uplift of initial fogs. The cloud often occurs at the inversion which caps the turbulence layers. Manley[2] observed that most of these stratus layers occur at between 400 feet and 2500 feet over Durham city. Usually the height of the cloud increases inland due to the relative warmth of land surfaces. The inner border of the cloud is often abrupt since it tends to coincide with transverse ridges. The escarpment of the east Durham plateau, the foothills of the Pennines and the Cross Fell escarpment have each been observed to limit the inland penetration of the cloud (Manley[2]). Lamb[1] noted that the cloud often penetrates farthest inland up valleys and gaps such as those of the Tyne, the Thames, the Forth lowlands and the Fens. Freeman[3] has constructed an isopleth map showing the gradual penetration of such a cloud cover into the Fens on one occasion. Apparently the cloud cover dis-

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[1] LAMB, H.H., 1943, op.cit.
[2] MANLEY, G., 1935, op.cit.
[3] FREEMAN, M.H., North Sea stratus over the Fens, Met.Mag. 91, 357, 1962.

solves rapidly after decay commences so that uniform sheets are much more common than globular masses (Bull[1]).

There is some confusion concerning both the regional and the seasonal distribution of the haar but this arises partly from a conflict of interest. Lamb[2] was concerned primarily with the hazards which the fog presents to coastal airfields. Manley[3] by contrast, was most interested in the stratus cloud over the interior. The coastal fog is little effected by interior temperatures or relief and so it is relatively common from Caithness to Lincolnshire (despite minor exceptions) and it occurs throughout spring and summer. However the stratus cloud is considerably effected by inland conditions. Hence Manley reported a more restricted regional distribution (Flamborough Head to the Firth of Forth) of high haar frequencies. Similarly, Manley's period of frequent haars, late April to late June, excludes the mid summer period of high land temperatures and Manley observed very few haars to occur over Durham after the beginning of July.

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[1] BULL, G.A., Stratus cloud near the east coast of Great Britain. <u>Professional Notes</u>, 103, 1951.
[2] LAMB, H.H., 1943, <u>op.cit</u>.
[3] MANLEY, G., 1935, <u>op.cit</u>.

The annual occurrences of haars are very variable and Manley[1] restricts himself to a rough estimate of mean frequencies of between five and ten occasions in late spring and early summer in north east England. Certainly there are some years without haars.

Following this general account of the haar there will now be examinations of its causes and its climatic effects. Both of these discussions will be concerned specifically with north east England though comparisons will be drawn from other areas where necessary.

B. CAUSES OF THE HAAR

The general processes of advection coöling and the associated cloud and fog formation require no discussion here. However an examination is required of the factors causing a relatively high frequency of stratus cloud over the lowlands of Northumberland and Durham in late spring and early summer. Three groups of factors, oceanographical, meteorological and topographical are operative in this respect and these will be examined individually.

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[1] MANLEY, G., 1935, op.cit.

1. OCEANOGRAPHICAL FACTORS

These involve the seasonal and areal variations in the surface temperature of the North Sea. They are partially responsible both for the frequent occurrence of the haar in late spring and early summer, and for its concentration along the east coast of England.

February and August are the months of extreme sea surface temperatures in the North Sea. However spring is the season of greatest relative coldness of the sea in comparison with the land. This is important to the study of the haar which is partly created by the advective cooling of continental air masses.

There are marked areal variations in surface temperatures. Throughout the year the lowest surface temperatures in the western part of the North Sea occur in a belt between 50 and 100 miles wide and adjacent to the east coast of Great Britain. In this cold belt monthly average sea surface temperatures are usually about 2°F lower than those in adjacent areas in the middle of the sea. On individual days this discrepancy may be much greater. For example on September 3rd 1958 the sea surface temperature at Berwick was 8°F lower than that 200 miles to the east in the middle of the North Sea (Lumb[1]).

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1. LUMB, F.E., Seasonal variations of the sea surface temperature in coastal waters of the British Isles. Scientific Papers, No.6, 1961.

A variety of processes has been invoked to explain the presence of this cold belt. Lamb[1] explained it simply in terms of an upwelling of cold water due to an eastward movement of surface water provoked by the prevailing winds. Stevenson[2] emphasised the importance of the fact that within this cold belt the water is practically isothermal with depth whereas in the middle of the North Sea there is a very rapid decrease of surface temperature with depth. Lumb[3] points out that in summer this isothermal state can only be explained in terms of mechanical mixing since the absorption of short-wave radiation at the surface tends to create ocean stability. This mechanical mixing may be due to the strong tidal current along the coast (the coastal tidal stream is roughly twice as fast as that in the middle of the North Sea) or to a southward current immediately offshore (Stevenson[4]). Since this current is from the north it will also tend to transport cold water southwards.

This cold tongue of water emphasises advective cooling in the same way as the cold Peruvian and Californian currents. Lamb[5] explains its particular signifi-

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[1] LAMB, H.H., 1943, op.cit.
[2] STEVENSON, R.E., Sea-breezes along the Yorkshire coast in summer of 1959. Met.Mag. 90, 153, 1961.
[3] LUMB, F.E., 1961, op.cit.
[4] STEVENSON, R.E., 1961, ibid.
[5] LAMB, H.H., 1943, op.cit.

cance to fog formation by emphasising its effects upon air stability. The cold tongue prolongs cooling until the westwards moving air masses reach the shore. Consequently cooling proceeds in the lowest air layer until the shore is reached and so a stable environmental lapse rate is preserved down to the surface.

2. METEOROLOGICAL FACTORS

These are mainly responsible for the seasonal distribution of the haar since spring is characterised by relatively high frequencies of anticyclones and northerly air-streams over north west Europe.

Both Belasco[1] and Levick[2] found September maxima plus May and June secondary maxima in the frequency of anticyclonic situations over the British Isles. However the September anticyclones are usually small, moving detachments of the Azores High and are frequently responsible for fine tropical maritime weather. By contrast the spring anticyclones are more persistent, are usually stationary to the north east of the British Isles and are associated with cold polar weather. This contrast be-

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[1] BELASCO, J.E., The incidence of anticyclonic days and spells over the British Isles. <u>Weather</u>, 3, 233, 1948.

[2] LEVICK, R.B.M., Fifty years of English weather. <u>Weather</u>, 4, 206, 1949.

tween the two types is summarised by the considerable spring maximum of anticyclonic blocking activity (Sumner[1]).

Wind data reflect these seasonal peculiarities of the atmospheric circulation. At Durham both north and north east winds are relatively common in late spring and early summer, and these are the prevailing winds in May (Figure 1). Similarly long-term analysis of British weather maps has shown a distinct maximum of 'northerly' and 'easterly' weather, and a minimum of 'westerly' weather in spring (Lamb[2]).

The effects of these changes in the atmospheric circulation upon the haar are two-fold. Simplest is the numerical factor. North and north east winds are two or three times more common in April, May and June than in other months and are partially associated with the haar. Therefore the haar is most likely to occur in spring.

Additionally the spring maximum in the frequency of anticyclonic situations is operative in this respect. Surface stability is essential for marked advective cooling since it reduces the thickness of the

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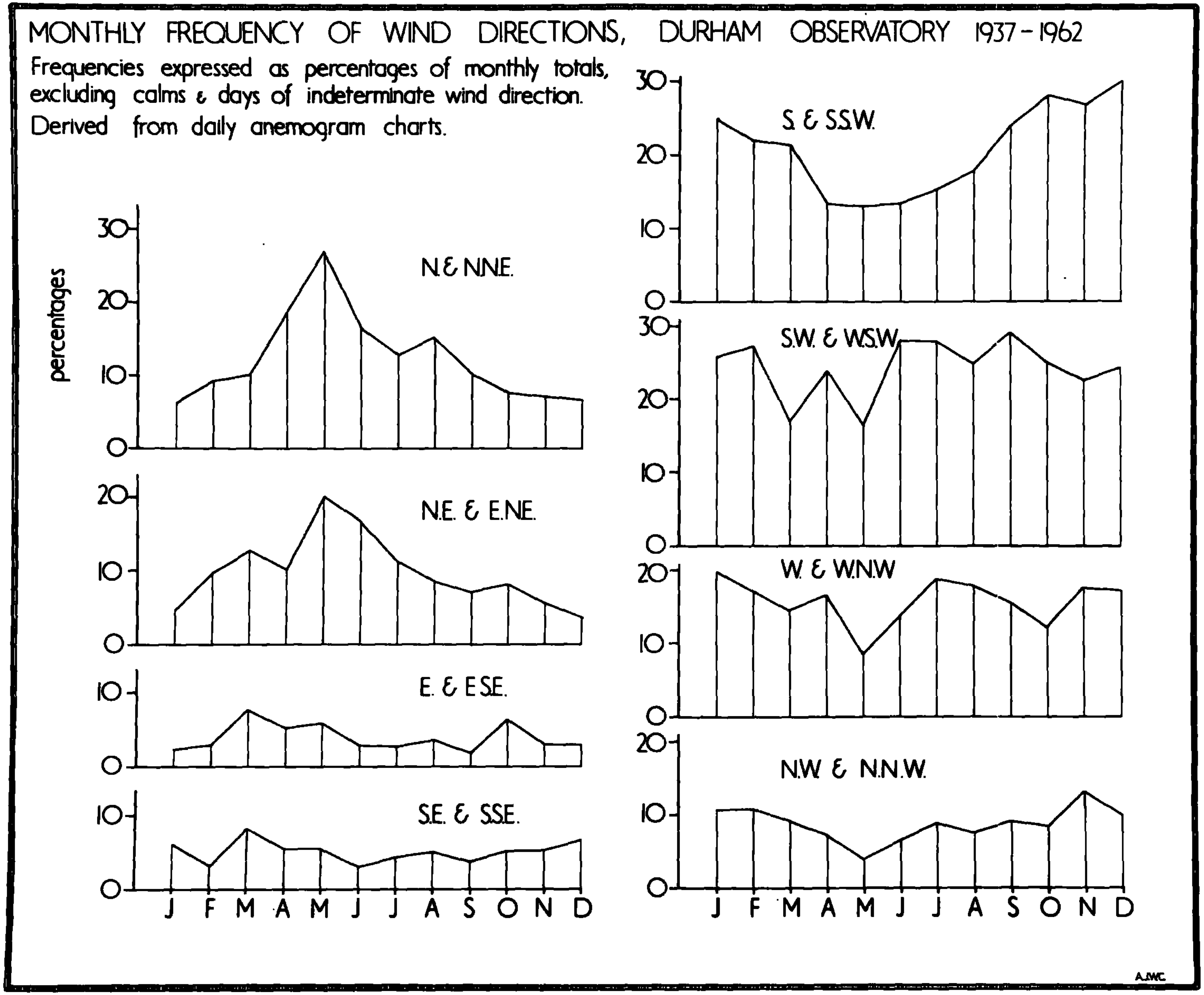
[1]. SUMNER, E.J., Blocking anticyclones in the Atlantic-European sector of the northern hemisphere. <u>Met.Mag.</u>, 88, 300, 1959.

[2]. LAMB, H.H., Types and spells of weather around the year in the British Isles: annual trends, seasonal structure of the year, singularities. <u>Quart.J.R.met.Soc.</u>, 76, 393, 1950.



MONTHLY FREQUENCY OF WIND DIRECTIONS, DURHAM OBSERVATORY 1937 - 1962

Frequencies expressed as percentages of monthly totals, excluding calms & days of indeterminate wind direction. Derived from daily anemogram charts.

FIGURE 1

turbulence layer to a minimum and so concentrates the cooling. The weak pressure gradients associated with anticyclones generate low wind speeds and this also minimises the depth of the turbulence layer. Findlater[1] has described a property of the lower layers of anticyclones which may be of specific relevance to the study of haars. Using upper air data he examined the thermal properties of these lower layers and noted that cells of warm and cold air are occasionally located at the inversion. These cells are not formed *in situ*; they appear to originate from air of tropical or polar origin which is incorporated into the anticyclone. Findlater noted that stratus and stratocumulus cloud at the level of the inversion is often associated with the cold ~~sp~~cells, partly because of their lower temperatures but mainly because they steepen the environmental lapse rate and decrease the stability of the air. This encourages the uplift of moisture to the inversion.

3. TOPOGRAPHICAL FACTORS

The eastern parts of Northumberland and Durham constitute a lowland between the Cheviots, the Pennines and the North York Moors. General elevations within the

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[1] FINDLATER, J., Thermal structure in the lower layers of anticyclones. *Quart.J.R.met.Soc.*, 87, 513, 1961.

lowlands are of the order of 200 feet though in the southern half there are considerable variations in elevation. Here the broad, lowlying vale of the Tees contrasts with the east Durham plateau. With elevations between 400 and 600 feet and culminating in a north to south escarpment some four miles to the east of Durham city,this is a major irregularity within the lowlands. (See Figure 2) The coastline is long, straight and cliffed and trends between north north west and south south east. It is exposed to all winds arriving between north and south east.

Manley[1] noted that on many occasions the limit of the stratus cloud coincides with north to south relief features. Presumably adiabatic warming to the lee of hills is responsible for this coincidence. Occasionally the west facing escarpment of the east Durham plateau functions in this way, more often the foothills of the Pennines or the Cross Fell escarpment form the western limit of the cloud. In either case it is clear that the low elevations of the lowland provide a general area into which incursions of stratus cloud are relatively common. Tributaries of the lowland such as Tynedale and Teesdale allow particularly deep incursions of cloud (see page 22).

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[1] MANLEY, G., 1935, <u>op.cit</u>.

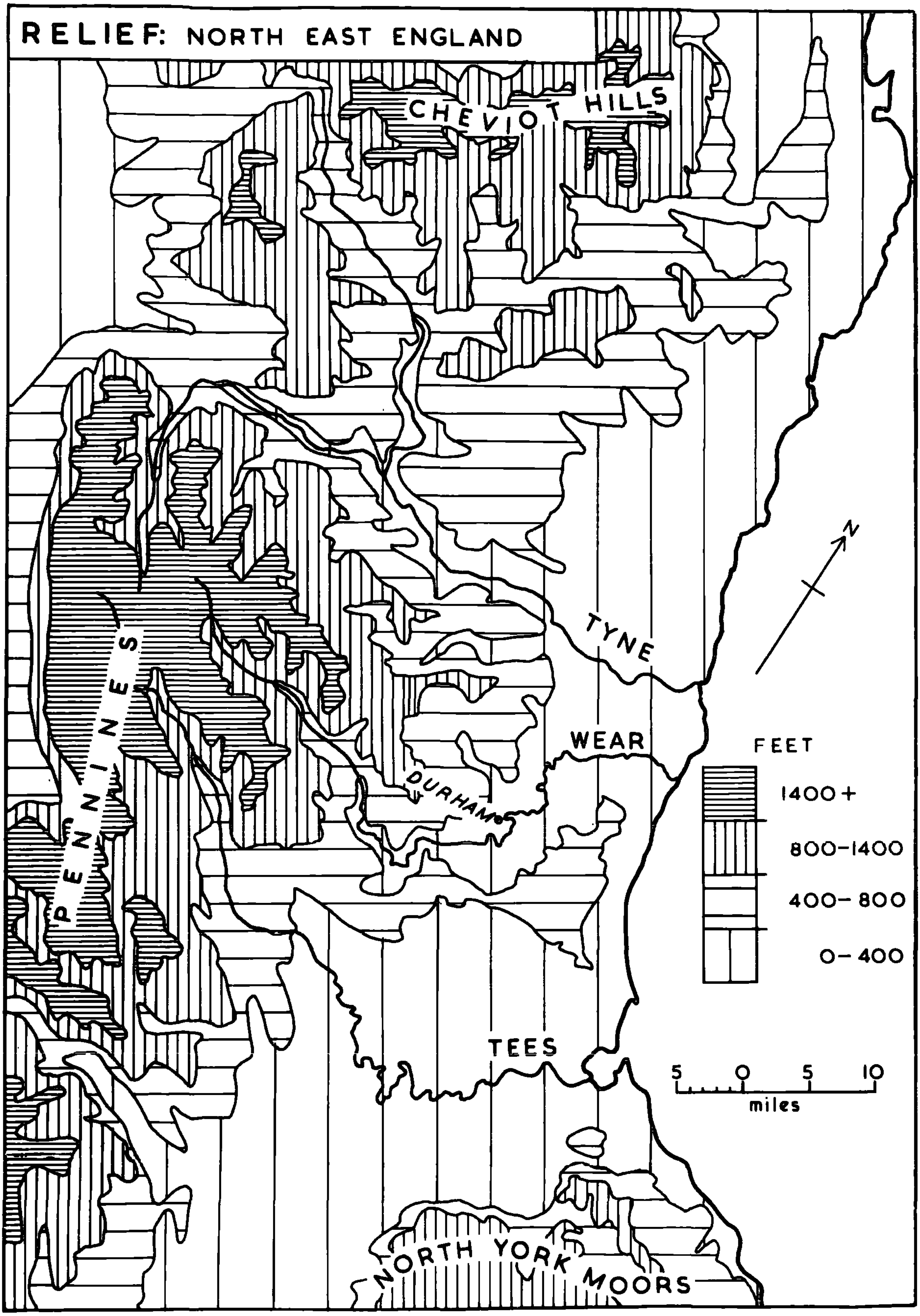
RELIEF: NORTH EAST ENGLAND
CHEVIOT HILLS
PENNINES
TYNE
WEAR
DURHAM
TEES
NORTH YORK MOORS
N
FEET
1400+
800-1400
400-800
0-400
5
0
5
10
miles

FIGURE 2

During periods of haars brought by south east winds it appears that a lee-clearing effect may operate over the North York Moors (Lamb[1]). Similar protection is given to the Firth of Forth and the Moray Firth. However Lamb also noted a tendency for minor lee depressions and troughs to be generated during periods of slack pressure gradient, high pressure and south east wind in the vale of Tees by the North York Moors. Locally this deflects the haar (and Tees-side smoke) towards Catterick.

There is a rapid uplift by some 200 feet along the cliffed coast and this may be sufficient to provoke or intensify cloud formation. Furthermore, in Durham elevations rise gradually up the dip slope of the plateau by a further 400 feet within about eight miles of the coast.

Finally the effects of industrial activity may be mentioned. Condensation nuclei are essential to haar formation and the local industry provides a secondary source of these. Lamb observed a case in which Tees-side smoke was blown out to sea and later returned by the sea breeze to bring a rapid onset of fog at Thornaby on Tees. Similar transfers of smoke have been observed especially during periods of horizontal sea breeze. It is also likely

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[1] LAMB, H.H., 1943, op.cit.

that haar conditions will intensify inland over an industrial region as a result of the supply of condensation nuclei in situ.

C. CLIMATIC EFFECTS OF THE HAAR

Although Manley[1] estimated a mean haar frequency of only between five and ten occasions throughout April, May and June, the phenomenon seems to modify the seasonal regimes of a number of elements. This modification is more pronounced with fog and sunshine frequencies than with cloud frequencies or temperature observations.

1. FOG FREQUENCIES

Particularly striking are the effects of the haar upon coastal fog frequencies. This is especially true of Scotland where much of the coast is remote from sources of air pollution. Lamb[2] asserts that the only common cause of bad visibility along much of the east coast of Scotland is the haar.

Fog durations are recorded by lighthouse keepers who are required to log the periods during which the fog-horn is sounding. This gives a subjective but detailed and

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[1] MANLEY, G., 1935, op.cit.
[2] LAMB, H.H., 1943, op.cit.

long record of fog durations. Hennessey[1] examined data of this kind recorded off the Humber and Wash. His results showed a winter maximum of fog frequency with a very slight secondary maximum in May at only a small number of stations. Significantly these secondary maxima in May were restricted to coastal stations including Flamborough Head and Cromer and were absent at Spurn Head and at offshore light vessels. The frequency of fog in May at Flamborough Head is not greater than that at Cromer according to these observations (see Table 1).

TABLE 1. MEAN MONTHLY FOG FREQUENCIES AT FLAMBOROUGH HEAD AND CROMER LIGHTHOUSES, 1919 - 1937

(fog duration expressed as a percentage of total hours per month)

	Jan.	Feb.	Mar.	Apr.	May	June
Flamborough	13	9	8	7	9	6
Cromer	13	12	9	7	9	5
	July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
Flamborough	7	6	6	6	9	12
Cromer	4	4	6	6	11	15

(after Hennessey)

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[1] HENNESSEY, J., Atmospheric obscurity in the approaches to the Humber and the Wash. The Marine Observer, 15, 150, 1938.

More intense haar effects are suggested by a similar analysis of Scottish data by Dixon.[1] This is especially interesting since it allows comparison of conditions on all Scottish coasts and the results are shown in Figure 3. The east coast suffers a much greater mean annual duration of fog than the west coast. Generally the maximum monthly duration of fog is in May on the east coast (except in the sheltered estuaries where it tends to be earlier) and July on the west coast. These maxima are quite pronounced (see Table 2).

TABLE 2. MEAN MONTHLY FOG FREQUENCIES AT TWO GROUPS OF SCOTTISH LIGHTHOUSES, 1925 - 1934 (in hours)

	Jan.	Feb.	Mar.	Apr.	May	June
East	9	14	25	25	37	28
North West	1	3	6	3	9	8

	July	Aug.	Sept.	Oct.	Nov.	Dec.
East	34	22	15	3	4	5
North West	15	8	5	2	1	0

(after Dixon)

East coast = seven lighthouses between Firth of Forth and Moray Firth.

North west coast = six lighthouses between Cape Wrath and Oban.

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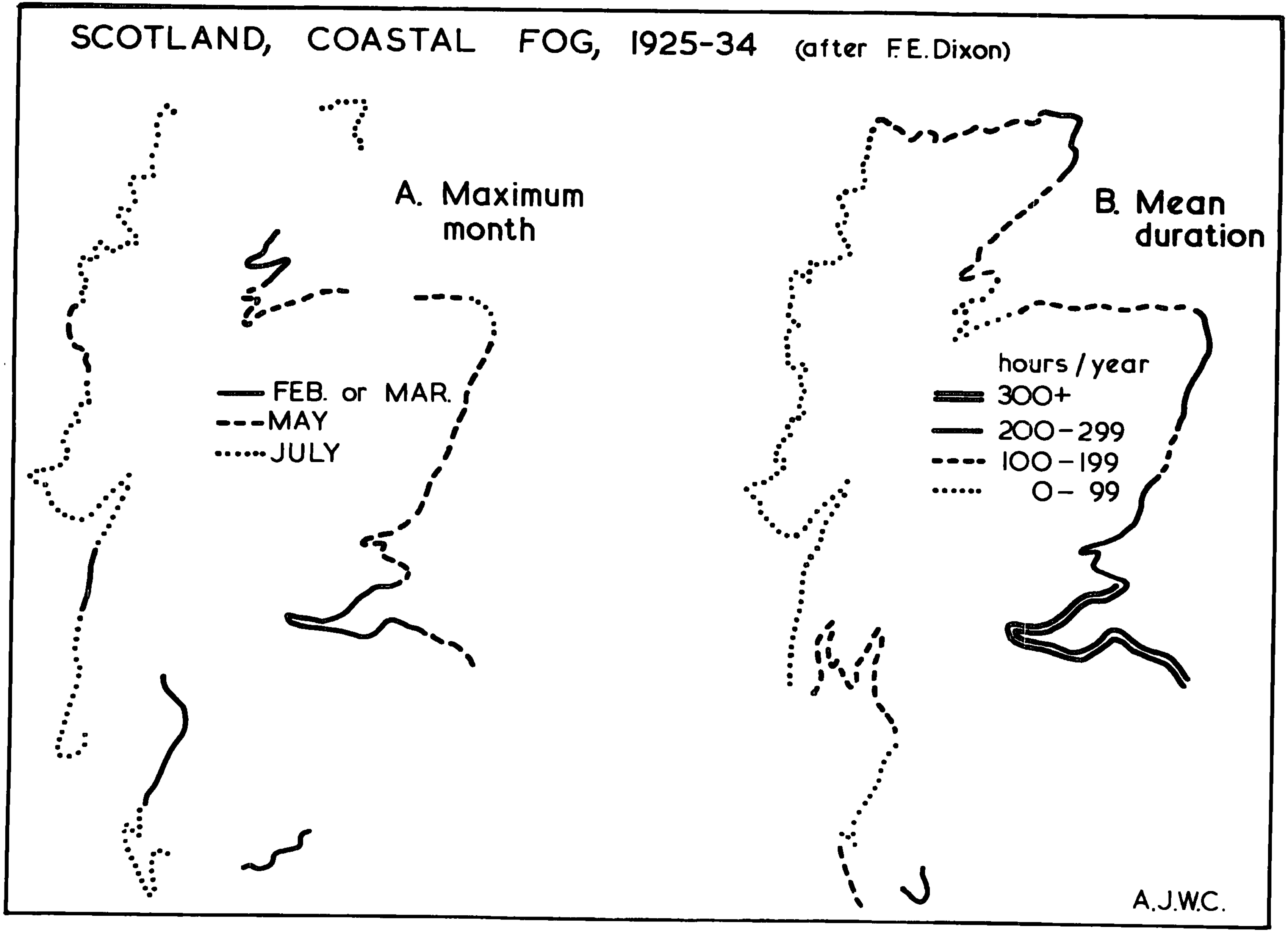
[1] DIXON, F.E., Fog on the mainland and coasts of Scotland. Professional Notes, 88, 1939.



SCOTLAND, COASTAL FOG, 1925-34 (after F.E. Dixon)

A. Maximum month

B. Mean duration

FIGURE 3

2. CLOUD FREQUENCIES

Cloud observations have neither the simplicity nor the high density of the previous fog observations and these may be important reasons why studies of cloud frequencies have failed to demonstrate a haar effect.

Caton[1] took advantage of the high density of cloud observations in eastern England during the war to prepare a promising analysis of the association between low stratus cloud and synoptic situation. Data from four stations, two coastal and two inland, in East Anglia and the east Midlands were analysed by comparing the relationships between six types of synoptic situation and six grades of stratus cover. However,since the analysis was performed only for 1944 it has little practical significance to the present study. In 1944 the frequency of north easterly and easterly winds was roughly 50 per cent above average in summer. Not surprisingly therefore stratus skies of all grades were associated more frequently with "north easterly" situations than with any other situation excluding "frontal" and "slack pressure gradient". While discussing the seasonal properties of "north easterly" situations in this respect Caton did not report a particularly close association with stratus cloud in spring.

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[1] CATON, P.G.F., Occurrence of low layer-type cloud over eastern England in relation to synoptic situation. Met.Mag., 86, 161, 1957.

Bull[1] examined the properties of low clouds associated with onshore winds (excluding sea-breezes) at Felixstowe between 1931 and 1938. He was primarily concerned with diurnal changes in the cloud cover and with its methods of formation and dissolution. Therefore he did not describe seasonal variations or mention a haar effect.

Recently Freeman[2] has attempted to remedy the low density of stations by creating a dense network of temporary stations over a small part of the Fens. The voluntary observers are required to note exactly the time of formation of low stratus cloud or fog on selected days with east winds in spring. As yet the experiment has only worked upon one occasion but that allowed the construction of an isopleth map showing the movement of the cloud inland.

3. SUNSHINE DURATION

Sunshine data are particularly useful for the study of the haar because of their simplicity and the high density of their observations, and because the haar is most common in the late spring, early summer period

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1. BULL, G.A., 1951, op.cit.
2. FREEMAN, M.H., 1962, op.cit.

of maximum sunshine durations. In Britain the mean annual duration of sunshine is usually greater along eastern coastal districts than along western districts. However, Manley[1] noted that in northern England the opposite applies since the stretch of coast between the Ribble and the Solway Firth has a higher mean annual duration of sunshine than that between the Humber and the Tweed. This deficiency of sunshine along the north east coast is wholly accummulated in April, May and June, the months of long daylight hours. It is attributed by Manley to both the haar and the tendency for unstable Arctic air masses to produce showers along the north east coast in spring. Glasspoole and Hancock[2] confirm that in all months there is either equality between these two coasts or else a maximum shunshine along the north east coast except in April, May and June when the relative deficiency here amounts to an average of about one hour per day.

4. SEASONAL TEMPERATURES

It is very difficult to estimate the effects of the haar upon mean seasonal temperatures because its

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1. MANLEY, G., 1935, op.cit.
2. GLASSPOOLE, J., & HANCOCK, D.S., The distribution over the British Isles of the average duration of bright sunshine: monthly and annual maps and statistics. Quart.J.R.met.Soc., 62, 247, 1936.

effects are dominated by zonal factors. In Britain the spring rise in temperatures appears to be reduced by a cooling effect. This is distributed throughout the country because it is due to the high frequency of northerly winds in spring. However different detailed studies of temperature have failed to agree upon the magnitude or duration of this cooling effect. Lamb[1] noted a recurring mid April 'cold' spell and an early May 'northerly and anticyclonic' spell in the British Isles over a 50 years period. Brooks[2], using rather similar data and techniques, was surprised to find no evidence of a May cold spell. Reynolds[3] analysed Liverpool temperatures and extracted a late April 'cold' spell but none in May, whereas Hawke[4] found a small secondary maximum in the frequency of 'cold days' in May at Greenwich using a century's observations. General air mass properties have a significant, though obscure, effect upon

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[1] LAMB, H.H., 1950, op.cit.

[2] BROOKS, C.E.P., Annual recurrences of weather: singularities. Weather, 1, 107 & 130, 1946.

[3] REYNOLDS, G., Short periods of unseasonal warmth or cold in daily mean maximum temperatures at Bidstone. Quart.J.R.met.Soc., 81, 613, 1955.

[4] HAWKE, E.L., The frequency-distribution around the year of abnormally high and low daily mean temperatures at Greenwich Observatory. Quart.J.R.met.Soc., 67, 247, 1941.

mean temperature regimes and it is unlikely that the effect of the haar will be noticable in this case. However Manley[1] did report a delay in the spring rise of temperatures in north east England which he attributed to the haar.

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[1] MANLEY, G., 1935, op.cit.

CHAPTER 2

DATA AND PROCEDURES

The previous chapter has shown that the haar modifies a wide variety of air mass properties and that its climatic effects are complex. This thesis focusses attention upon only a few of these effects. It is concerned only with conditions inland from the coast and it uses data drawn entirely from the record of Durham Observatory. Since this is located some twelve miles inland it experiences stratus cloud rather than fog formation. This cloud occurs mainly in late spring and early summer. It brings cool, sunless conditions to Durham city on days which would otherwise be warm and sunny.

This thesis estimates the total effects of the haar upon the maximum temperature and sunshine duration records of the observatory. These analyses are intended to provide indirect measures of the magnitude of the haar effect.

The present chapter will examine first the general considerations leading to the choice of data and it will later outline the procedures to be adopted in their analysis.

A. THE DATA

1. MAXIMUM TEMPERATURE

The haar provokes coolness by two processes. These include advective cooling over the sea and the interception of short wave radiation by the cloud cover over the land. The first of these processes encourages low temperatures by both night and day, while the second encourages relatively high night temperatures. Therefore, while it is desirable that some measure of daily warmth should be used in this analysis, clearly this must refer specifically to daytime conditions. This is an important reason why daily maximum temperatures, rather than a mean temperature based upon the maximum and the minimum has been adopted. Reynolds[1] used maximum temperatures in his study of daily warmth at Bidstone since he also objected to the depression of the minimum temperature on fine days and since he considered that "warmth" is merely an environmental response of man who is inactive at night.

However this usage of the daily maximum temperature suffers from its sensitivity to short bursts of sunshine in summer. Unfortunately these are likely to occur

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[1] REYNOLDS, G., Short periods of unusual warmth or cold in daily mean maximum temperatures at Bidstone. Quart.J.R.met.Soc., 81, 613, 1955.

in the latter part of the haar period and this corresponds with the maximum elevation and heating power of the sun. In Part 3 it will be shown that the regression of maximum temperature upon sunshine duration at Durham is such (on days with north east winds) that the average increase in maximum temperature per one hour increase in sunshine duration is 0.7°F in April, 0.8°F in May and 1.0°F in June (see Table 42). In June the average maximum temperature at Durham on days with north east winds is 57°F when the sunshine duration is between 0.0 and 0.9 hours and it is 60°F with durations from 1.0 to 1.9 hours. This problem could have been partly remedied by using a daily mean temperature based upon dry-bulb observations at specific hours during the day if these were available.

2. SUNSHINE DURATION

However, there are greater difficulties associated with the description of the cloud element of haar weather because of its complexity and because its observations are non-instrumental and subjective. It is inadequate to use the cloud observations of a normal climatological station in this respect. Layer clouds are created by a wide variety of processes and are very common (particularly during the night and at 09.00 and 21.00 hours). Those due to orographic uplift of moist, stable air masses are likely to be especially common with easterly winds at Durham since it occurs to the east of the Pennines.

There are at least two peculiarities of the haar stratus at Durham and neither of these can be detected from the cloud record of the observatory. The cover is very persistent during the day but when clearing commences it is quite rapid. Additionally the cover is very low. Common elevations are between 400 feet and 2500 feet at Durham and occasionally the top of the cathedral tower alone is obliterated by the cloud. Only records of daytime cloud conditions and cloud height could help to distinguish haar stratus from other forms of stratus cloud.

Sunshine duration has been used as a measure of the cloud element basically because the sunshine record refers to total daytime conditions and because it is relatively objective. A fortuitous advantage of this usage of the sunshine record is the fact that the period of maximum daylight hours is close to the peak haar period. A consultation of monthly mean sunshine durations in eastern England has already suggested that these appear to be modified by the haar effect and this modification is especially pronounced in north east England (page 23).

3. WIND DIRECTION

An estimate of mean daily wind direction, rather than spot observations at 09.00 and 21.00 hours is used in this analysis. The basic objection to the use of the manual record is its failure to detect the very wide hourly variations to which wind direction is prone in the mid-latitudes.

The record of the Dines Anemometer was used for this estimation of mean daily wind direction. The preserved anemometer record dates from July 1937 to June 1962 and this has dictated the limits of the period of the present analysis - 25 years from July 1937 to June 1962.

The anemographs for each day during this 25-year period were examined and, where possible, they were classified, visually, into one of the 16 major points of the compass. Later this classification was simplified by combining the directions to form eight as follows:

north + north north east = N
north east + east north east = NE
east + east south east = E
south east + south south east = SE
south + south south west = S
south west + west south west = SW
west + west north west = W
north west + north north west = NW

Throughout this text capital abbreviations when used to denote wind direction will refer to these pairings. Also it will occasionally be convenient to group these divisions into two halves since winds between north and south south east are onshore along the east coast. The term "eastern group of winds" will be used to distinguish these winds from the "western group" which includes all remaining winds.

Although laborious, this method of estimating mean daily wind direction is subjective. However more precise arithmetical or graphical techniques of examining the anemographs are inapplicable in long-term analyses.

Occasionally it was impossible to estimate a mean wind direction of course. Various factors, including frontal wind change, occurrence of calms or failure of the instrument caused these omissions. In all months a mean wind direction could be allotted to at least an average of over three quarters of the total number of days (see Table 3).

TABLE 3. MONTHLY FREQUENCIES OF DAYS ON WHICH NO MEAN WIND DIRECTION WAS ESTIMATED, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	Jan.	Feb.	Mar.	Apr.	May	June
mean	4.0	4.2	5.2	4.6	5.3	6.1
maximum	10	16	11	11	11	14
	July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
mean	6.8	6.0	4.5	4.3	4.2	4.1
maximum	12	11	8	13	8	9

Possibly the summer maximum in Table 3 is caused by a greater frequency of calms at that time.

B. PROCEDURES

The analysis commences with the tabulation of the data on a daily basis. Where possible, values of mean wind direction, maximum temperature and sunshine duration for each day between July 1937 and June 1962 are extracted from the record of Durham Observatory.

In Chapters 3, 4 and 5 daily maximum temperature and sunshine duration, respectively, are examined along similar lines. The purpose of these analyses is to study the variations of these elements according to wind direction and time of year. In both cases there is an initial classification of the data into 96 frequency distributions each referring to a particular month and one of eight wind directions. For example, all daily maximum temperatures observed with N winds in January are grouped together as are those with NE winds in January etc. Frequency distributions are prepared for each of these groups in both graphical and tabular forms.

Initially the properties of these frequency distributions are described on a monthly basis.

In Chapter 3 these monthly accounts describe the variations according to wind direction of three properties of the daily maximum temperatures. These properties are the mean, the standard deviation and the skewness. Later there is a discussion of the relevance of these results to the study of the haar.

The main part of the sunshine duration analysis is contained in Chapter 5. This commences with monthly accounts of the variations of sunshine duration according to wind direction. The three properties of sunshine duration included in these monthly accounts are the mean daily sunshine duration, the percentage frequency of sunless days and the percentage frequency of days with less than 10% of the possible sunshine duration. Again a general discussion follows these monthly accounts.

Part 1 concludes with a criticism of these methods in Chapter 6.

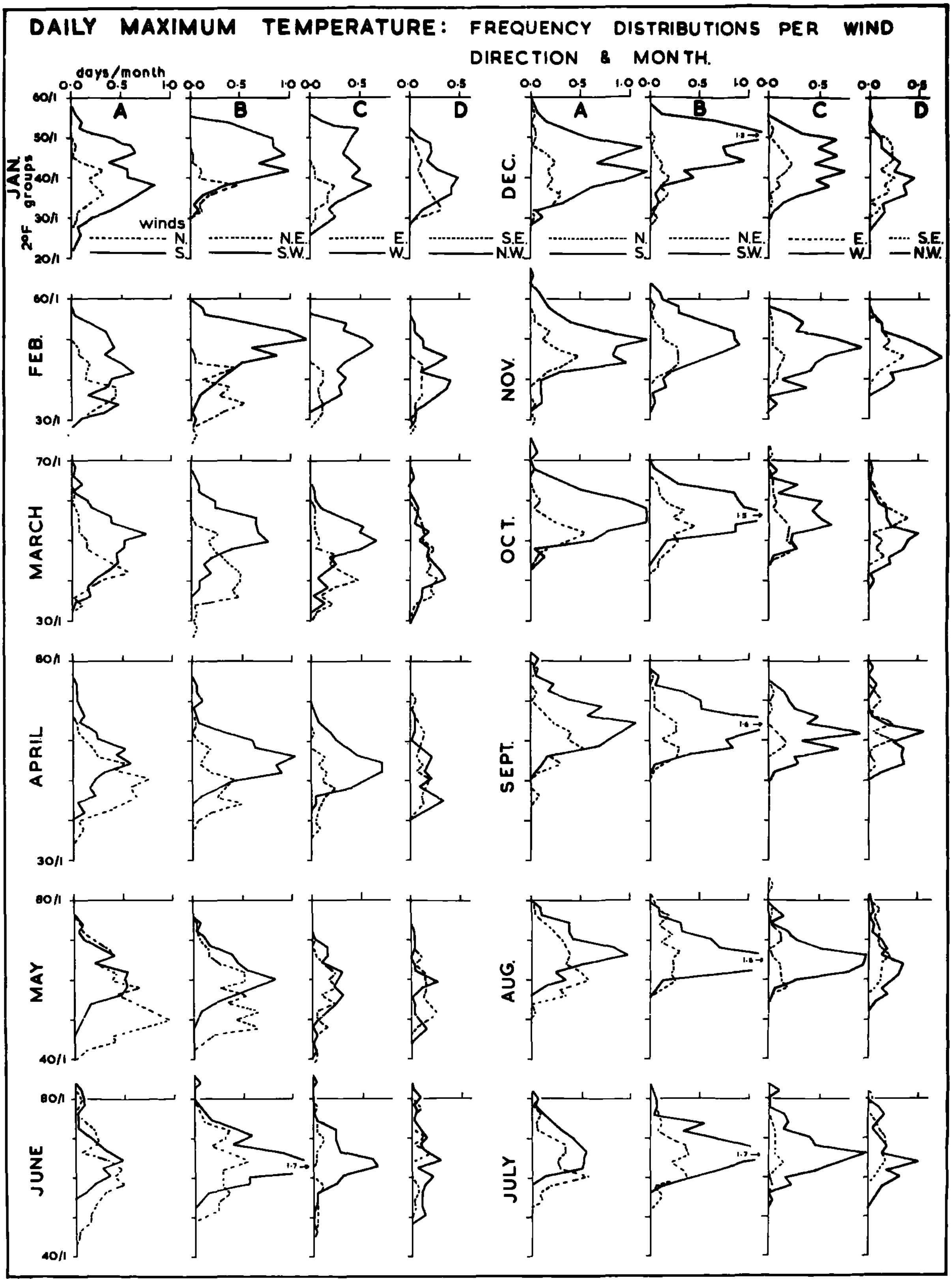
CHAPTER 3

ANALYSIS OF DAILY MAXIMUM TEMPERATURES

This analysis is basically designed to determine whether there are any peculiarities within the record of daily maximum temperature at Durham Observatory which can be ascribed to the effects of the haar. If these peculiarities are pronounced they may be used to describe the frequency and magnitude of this effect.

The method adopted in the analysis evolves from the assumption that the haar associates the eastern group of winds with relatively low daytime temperatures at certain times of the year. Consequently the daily maximum temperatures for the whole of the 25 year period from July 1937 to June 1962 are initially classified into 96 frequency distributions each referring to a particular wind direction and month. This is intended to portray the maximum temperature properties of days with each wind direction in all months.

Figure 4 contains these frequency distributions in a slightly modified form. Each of the graphs in this diagram contains two frequency distributions and this duplication is intended to halve the size of the diagram. For convenience, in all cases the frequency distributions which are



DAILY MAXIMUM TEMPERATURE: FREQUENCY DISTRIBUTIONS PER WIND DIRECTION & MONTH.

FIGURE 4

superimposed refer to opposite wind directions. This has the advantage of superimposing very different curves which are unlikely to be confused. The solid curves are always used for winds of the western group and the dashed curves are used for the eastern groups as follows:

COLUMN	DASHED CURVE	SOLID CURVE
A	N winds	S
B	NE	SW
C	E	W
D	SE	NW

A further modification in Figure 4 involves the fact that the temperatures on the x-axes are plotted in 2°F groups whereas in the original frequency distributions they were listed in units of 1°F. This is designed only to emphasise the basic form of each curve at the expense of accidental irregularities and all subsequent calculations based upon these frequency distributions employ the original 1°F units.

A glance at Figure 4 indicates that the maximum temperature properties of days with different wind directions are remarkably variable. Naturally the most pronounced contrasts are between different months but within the months there appear to be considerable variations between the means, dispersions and skewness' of individual curves. Note, for example, the difference in mean maximum temperature between days with NE winds and those with SW winds in February. There appears to be a much greater dispersion of maximum temperature on days with NE winds in May than on days with SW winds in August. Similarly the pronounced positive skewing of the curve referring to N winds in August contrasts with the negative skewing of that referring to SW winds in February.

This chapter will describe the contrasts between the frequency distributions in Figure 4 . A monthly basis will be used for this description. Each month will be examined in turn and the means, standard deviations, and skewness', of maximum temperatures observed on days with each wind direction will be described. Following this there will be a discussion of these results and this will examine their relevance to the haar.

A. MONTHLY ANALYSIS

1. JANUARY

Data referring to the mean, standard deviation and skewness of maximum temperatures observed on days with each wind direction in January are given in Table 4.

TABLE 4. JANUARY: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	39.0	38.3	36.7	37.3	41.2	46.3	42.6	40.3
B.	3.5	3.4	2.9	4.8	6.5	3.8	6.3	4.7
C.	107	142	75	147	126	95	105	105

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = measure of skewness: percentage ratio between mean deviations above and below the mean

$$C = \frac{\text{mean deviation above mean}}{\text{mean deviation below mean}} \times 100$$

Variations of maximum temperature according to wind direction in January are clearly dominated by the great thermal contrasts between maritime and continental influences at this time. The monthly mean maximum temperature in January (Durham Observatory, July 1937 to June 1962) is 42.1°F but the mean maxima observed with individual wind directions vary widely from this value. The winds of the eastern group all have mean maxima below this monthly mean maxima and in the extreme case, with E winds, this discrepancy amounts to 5.4°F. Of the western group of winds only SW winds have mean maxima substantially greater than the monthly mean maxima (an elevation of 4.2°F). Between the extremes observed with E and SW winds the

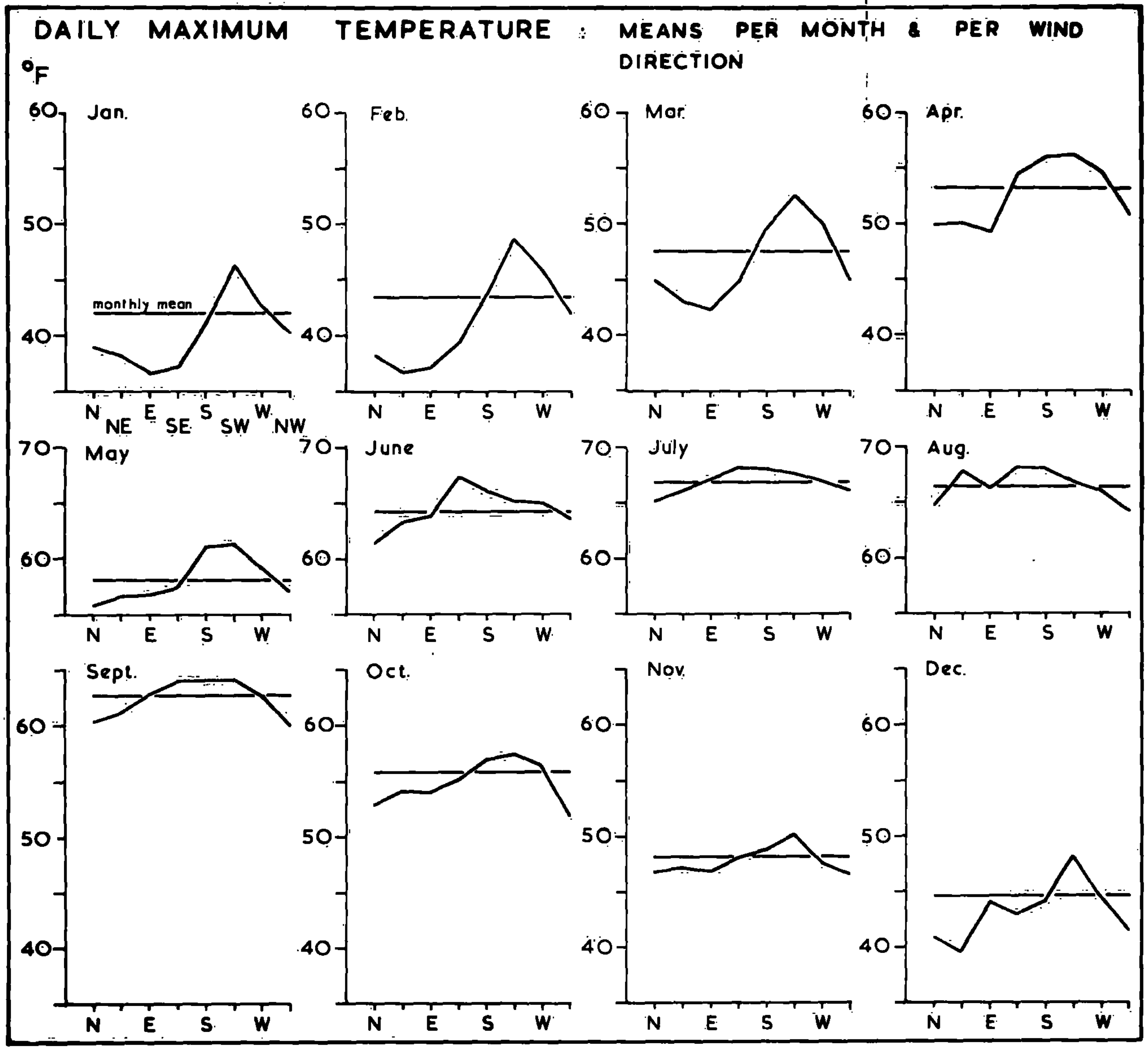

DAILY MAXIMUM TEMPERATURE : MEANS PER MONTH & PER WIND DIRECTION
°F
Jan.
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
monthly mean
60
50
40
70
N
NE
E
SE
S
SW
W
NW

FIGURE 5

curve of mean maximum temperature is smooth (see Figure 5).

Standard deviations of maximum temperature in January vary less regularly according to wind direction than the means. A casual glance at Table 4 suggests that a basic contrast exists between the eastern and western groups of winds. Standard deviations of maximum temperature observed with the western group are generally higher than those with the eastern group of winds. Closer inspection indicates important exceptions to this generalisation because a relatively high standard deviation is observed with SE winds and a relatively low one is observed with SW winds (see Figure 6). Therefore it appears that the high mean maximum temperature observed with SW winds in Table 4 is composed of individual values which, in relative terms, are uniformly high. Similarly the low mean maximum temperatures with E, NE, and N winds are composed of uniformly low individual values.

The percentage ratio between mean deviations above and below the mean in Column C of Table 4 provides a measure of skewness. Percentage ratios above 100% demonstrate positive skewness. The data show that in the case of NE, SE, and S winds unusually low maximum temperatures are more common than unusually high maxima. All of the remaining winds,excepting E winds, have fairly symmetrical distributions of maximum temperatures about

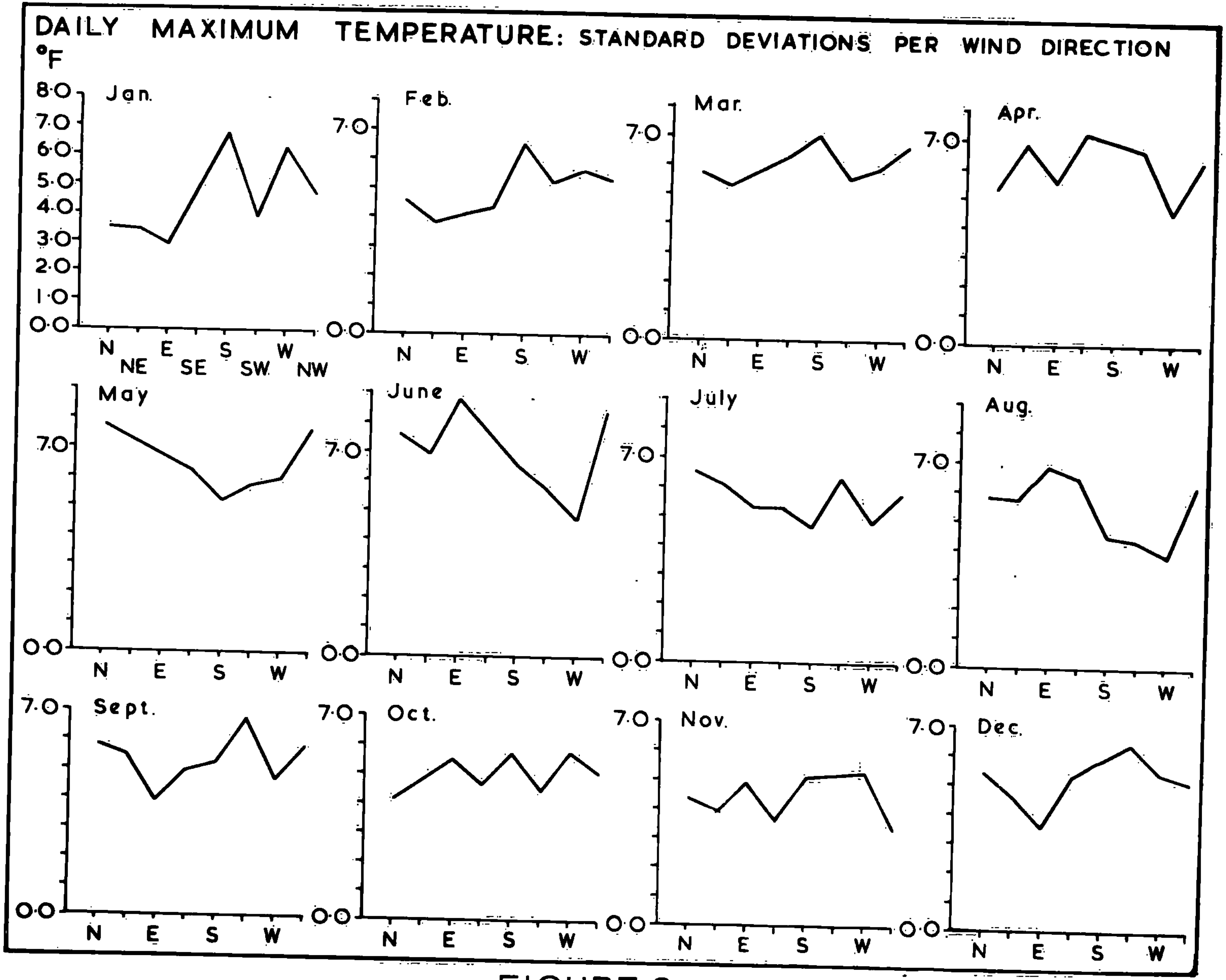

DAILY MAXIMUM TEMPERATURE: STANDARD DEVIATIONS PER WIND DIRECTION
°F
8·0
7·0
6·0
5·0
4·0
3·0
2·0
1·0
0·0
Jan.
N
NE
E
SE
S
SW
W
NW
Feb.
Mar.
Apr.
May
June
July
Aug.
Sept.
Oct.
Nov.
Dec.
7·0
0·0
N
E
S
W

FIGURE 6

the mean. In the case of E winds unusually high maxima are relatively common.

2. FEBRUARY

TABLE 5. FEBRUARY: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	38.3	36.7	37.1	39.3	43.3	48.6	45.8	41.8
B.	4.6	3.8	4.1	4.3	6.5	5.2	5.6	5.3
C.	134	118	115	88	107	73	68	144

A = mean maximum temperature,°F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

The dominance of the thermal contrast between continental and maritime influences, noted in January, is more pronounced in February and in this month it reaches its peak. Again the mean maximum temperatures observed with individual winds are distributed upon a smooth curve but in this case the extremes deviate further from the monthly mean maximum temperature of 43.5°F. The highest mean maximum, observed with SW winds, exceeds this monthly mean maximum by 5.1°F and the lowest mean maximum, observed with NE winds in this case, is 6.8°F below the monthly mean maximum.

Similarly in February there is no basic change in the relationship between standard deviation of maximum temperature and wind direction from that noted in January. Relationships which were merely developing in January are more fully developed in February because the contrast between low standard deviations with winds of the eastern group and higher standard deviations with those of the western group is now observed without major exceptions. Again the peak standard deviation is with S winds.

In February there is a tendency for positive skewing with NW, N, NE and E winds and negative skewing with SW and W winds. This parameter varies more smoothly in February than in January.

3. MARCH

TABLE 6. MARCH: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	44.9	43.0	42.4	44.8	49.5	52.6	50.0	45.0
B.	5.7	5.3	5.8	6.3	7.0	5.5	5.9	6.6
C.	105	121	161	98	95	87	77	159

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

March retains the relationships noted in the previous two months, though there is a retreat now from the extreme patterns of February. The mean maximum temperatures per wind direction are distributed upon a smooth curve of similar form to those of January and February and in this case the extreme deviations from the monthly mean maximum temperatures (47.4°F) are +5.2°F with SW winds and -5.0°F with E winds.

The general increase in the standard deviations of maximum temperature observed with most winds between January and February is more pronounced between February and March. While S winds retain a relatively high peak and NE winds retain a low trough in the standard deviation curve (Fig. 6) the general contrast between the winds of the eastern and western groups is no longer apparent in March. This is due to a relative decrease in this parameter with SW and W winds.

There is no basic change in the variation of skewness between February and March although the positive skewness with N winds is now much reduced and that with E winds is increased.

4. APRIL

TABLE 7. APRIL: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	49.8	50.0	49.4	54.6	56.0	56.2	54.8	50.7
B.	5.3	6.8	5.5	7.2	6.9	6.6	4.5	6.3
C.	98	121	115	105	102	139	121	100

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

While in April the contrast between relatively low mean maximum temperatures with winds of the eastern group, and relatively high values with the winds of the western group is retained, there is an important modification in the details of the curve in Table 7. Between March and April there is a relative increase in mean maximum temperature with S and SE winds so that the peak of this curve has moved counter-clockwise (see Figure 5) and has a more southerly component than in late winter. Additionally in April the extreme deviations of mean maximum temperature are less than before. The peak, with SW winds, only exceeds the monthly mean maximum (53.3°F) by 2.9°F and the trough, with E winds, deviates by only 3.9°F from this monthly mean maximum. Finally the April curve is unusual because it is no longer smooth. The mean maximum temperature observed with E winds is slightly lower than a smooth curve connecting the means observed with N, NE, SE and S winds.

There are no general contrasts between the standard deviations observed with the winds of the eastern and western groups respectively in Table 7. Therefore in this respect April differs from the earlier months which had established a rule that high standard deviations are observed with winds of the western group.

Similarly the pattern of skewness has altered by April since the high positive skewness with NE and E winds is now matched by that with SW and W winds.

5. MAY

TABLE 8. MAY: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	55.8	56.7	56.9	57.5	61.3	61.5	59.4	57.2
B.	7.7	7.2	6.7	6.2	5.2	5.7	5.9	7.5
C.	124	122	77	120	111	128	96	75

A = mean maximum temperatures, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

Between April and May there is a further modification in the curve of mean maximum temperatures. This modification is mainly concerned with the trough of the curve rather than its peak (Figure 5). N winds now have the lowest mean maximum temperatures since there has been a considerable relative warming of days with E winds between April and May. Despite this there is a relatively slow rate of increase in mean maximum temperature between N and SE winds in May. The total range of mean maximum temperatures is further reduced by May since the highest mean (with SW winds) only exceeds the monthly mean maximum of 58.1°F by 3.4°F while the lowest value is only 2.3°F below this monthly mean maximum.

The variations of standard deviation in Table 8 are a reversal of the patterns observed previously in late winter because the largest values in this case are observed with winds of the eastern group. In May the lowest standard deviation is observed with S winds which, previously, were associated with the highest values. The standard deviations observed with N, NE, E and NW winds in May are among the highest observed under any circumstances in this analysis and they demonstrate that these winds are associated with extremely wide fluctuations in maximum temperature.

Skewness in May is less pronounced than in late winter and, generally, it is positive. Exceptions to this rule occur with E and NW winds.

6. JUNE

TABLE 9. JUNE: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	61.5	63.4	63.9	67.3	66.2	65.2	65.0	63.6
B.	7.6	6.9	8.8	7.7	6.5	5.7	4.7	8.4
C	112	89	69	120	138	157	125	119

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

The counter-clockwise rotation in the direction of winds of highest mean maximum temperatures continues into June since in Table 6 SE winds are warmest. As in May the lowest mean maximum temperature occurs with N winds. That observed with E winds is again relatively low because it falls below a smooth curve connecting the mean values observed with N, NE and SE winds (Figure 5). The total range of values in June is comparable to that of May since the extreme deviations above and below the monthly mean maximum (64.3°F) are 3.0°F and 2.8°F respectively.

Standard deviations of maximum temperature in June resemble those of May because they are usually much higher with winds of the eastern than with those of the western group, although NW winds must again be classed with the eastern group in this respect. The highest standard deviations of maximum temperature observed under any circumstance in this analysis occurred with E and NW winds in June,and those with SE, N and NE winds in June are also exceptionally high.

The pattern of skewness continues to alter between May and June. In June maximum temperatures observed with winds of the western group are usually positively skewed whereas those observed with NE and E winds have a considerable negative skew.

7. JULY

TABLE 10. JULY: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	65.1	66.2	67.1	68.2	68.0	67.6	66.9	66.0
B.	6.5	6.1	5.3	5.3	4.6	6.3	4.8	5.7
C.	122	100	115	106	119	141	97	156

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

In July the distribution of mean maximum temperatures in relation to wind direction is quite symmetrical (Figure 5). As in June the highest values are observed with SE winds and the lowest with N winds. However in July these extremes are connected by a very smooth curve. The total range in mean maxima is very low. The monthly mean maximum temperature is $66.9^{\circ}F$ and this is only $1.3^{\circ}F$ lower than the highest mean and $1.8^{\circ}F$ greater than the lowest mean in Table 10.

The variations of standard deviation in July are less pronounced and more irregular than those of June. Particularly striking are the relatively low standard deviations observed with E and SE winds and the relatively high values observed with SW winds. The result of this is that in both absolute and relative terms maximum temperatures are much less variable in July than in June.

Positive skewness is common in July and this is most marked with NW and SW winds. However symmetry is observed with NE, SE and W winds, as shown in Table 10.

8. AUGUST

TABLE 11. AUGUST: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	64.7	67.8	66.3	68.0	67.9	66.8	66.0	64.1
B.	5.8	5.7	6.8	6.4	4.4	4.3	3.8	6.1
C.	133	102	168	128	94	123	120	117

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

In August the counter-clockwise movement of the wind direction of highest mean maximum temperature is most pronounced because, while in this month SE winds are still the warmest, NE winds are within 0.2°F of having the highest mean maximum temperature. Again in August there is a slight irregularity with E winds because these have a relatively low mean maximum temperature (Figure 5). NW winds are now the coldest. The total range of mean maxima is still low in August because the highest value exceeds the monthly mean maximum (66.5°F) by only 1.5°F and the lowest value is only 2.4°F below this mean.

In August there is a pronounced return to the conditions of May and June in terms of the standard deviation of maximum temperature. Admittedly these standard deviations are of lower magnitude in August than in May or June but they have relatively high values with winds of the eastern group. As in June the highest standard deviations are observed with E and SE winds.

Positive skewness predominates in August. It is very pronounced with E winds and moderately pronounced with N, SE, SW and W winds.

9. SEPTEMBER

TABLE 12. SEPTEMBER: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	60.4	61.3	62.9	64.0	64.2	64.3	62.7	60.2
B.	5.8	5.5	3.9	5.0	5.2	6.7	4.7	5.8
C.	102	102	109	100	124	124	105	121

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

Between August and September a return to winter conditions begins but it is not pronounced. The wind direction of highest mean maximum temperature moves clockwise to SW but there is still a general peak between SW and SE (Figure 5). This curve of mean maximum temperatures is smooth and of small amplitude. The highest mean maximum temperature exceeds the monthly mean maximum temperature (62.9°F) by only 1.4°F and the lowest mean maximum (with NW winds) is only 2.7°F below this mean.

The standard deviations in Table 12 also show the beginnings of a return to the winter pattern because a relatively low value is observed with E winds and a high value is observed with SW winds. Again this return is incomplete and these extremes are only minor irregularities from a fairly uniform curve.

Maximum temperatures are positively skewed with S, SW and NW winds. In all other cases they are fairly symmetrical.

10. OCTOBER

TABLE 13. OCTOBER: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	53.0	54.2	54.1	55.2	57.0	57.5	56.6	51.9
B.	4.1	4.8	5.5	4.6	5.7	4.4	5.8	5.0
C	139	117	150	85	108	112	114	139

A = mean maximum temperatures, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

The clockwise rotation of the wind direction of highest maximum temperature continues between September and October, so that in October SW winds are well established as the warmest winds. SE winds are now much cooler, in relation to SW winds, than was the case in September. Furthermore, both E and SE winds are relatively cool in terms of a smooth curve connecting NE and S winds (Figure 5). However the total amplitude of the October curve of mean maximum temperatures is still much less than was the case in late winter. While the extreme deviation below the monthly mean maximum temperature of 55.9°F is 4.0°F (with NW winds), that above this mean is only 1.6°F.

Standard deviations of maximum temperature vary irregularly according to wind direction in October. There is no general contrast between the winds of the eastern and those of the western groups in this respect.

Maximum temperatures observed with E, N and NW winds in October have pronounced positive skewing. Less pronounced positive skewing is observed with NE, S, SW and W winds.

11. NOVEMBER

TABLE 14. NOVEMBER: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	46.7	47.1	46.7	48.0	48.7	50.1	47.6	46.6
B	4.4	3.9	4.9	3.6	5.1	5.2	5.3	3.2
C	74	140	171	136	86	107	78	74

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

Between October and November the reversion to the mid winter pattern of mean maximum temperatures is again slow. The peak with SW winds is more pronounced by November but the total range of mean maximum temperatures is still relatively low. The highest value exceeds the monthly mean maximum (48.2°F) by only 1.9°F and the lowest mean maximum (with NW winds) is still only 1.6°F below this mean. E winds again have a relatively low mean maximum temperature.

Standard deviations of maximum temperature in November are relatively great with S, SW and W winds, and relatively small with NW, NE and SE winds. This suggests an incomplete return to the late winter pattern of standard deviations.

Similarly, the high positive skewness with NE, E and SE winds plus the negative skewness with S and W winds is indicative of late winter conditions. The high negative skewness with N winds is a major deviation from this generalisation.

12. DECEMBER

TABLE 15. DECEMBER: MAXIMUM TEMPERATURES RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	40.8	39.6	43.9	42.8	44.1	48.2	44.5	41.4
B	5.4	4.6	3.5	5.3	5.9	6.4	5.4	5.1
C	107	90	68	83	109	86	104	133

A = mean maximum temperature, °F

B = standard deviation of maximum temperature, °F

C = skewness (as in January)

In December the form of the curve of mean maximum temperatures closely approaches that of the January curve. There is a sharp peak with SW winds and a sharp trough with NE winds. The total range of observations is now considerably greater than in November. The monthly mean maximum temperature of 44.6°F is 3.6°F below the highest mean and it is 5.0°F greater than the lowest mean.

Similarly, standard deviations of maximum temperature in December resemble those of the following three months since in Table 15 the standard deviations observed with the winds of the western group tend to be greater than those observed with the winds of the eastern group. This is especially true if S and SW winds are compared with NE and E winds.

However the negative skewing observed with NE, E and SE winds in December conflicts with the positive skewing observed with these winds in the three following months.

B. DISCUSSION

1. MEAN MAXIMUM TEMPERATURE

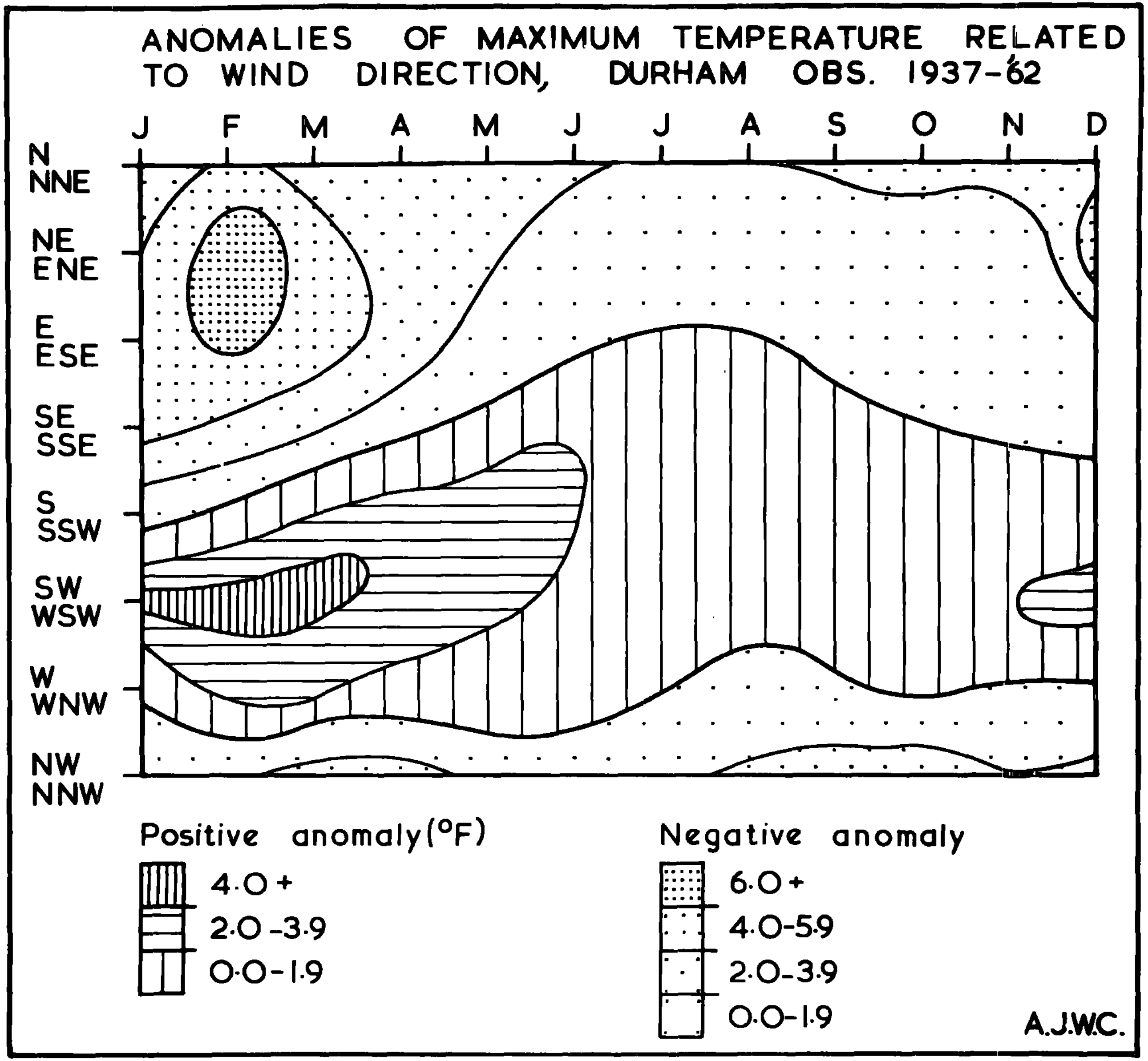
It has been shown that mean maximum temperatures can vary widely between days with individual wind directions in most months. This is because there is often a substantial difference, or anomaly, between the monthly mean maximum temperature and the means observed on days with individual wind directions. Usually negative anomalies (means per wind direction lower than the monthly mean) are most pronounced with winds of the eastern group while positive anomalies are most pronounced with those of the western group. For example, the largest negative anomaly (6.8° F) occurred on days with NE winds in February and the largest positive anomaly (5.2°F) occurred on days with SW winds in March. In the present analysis it is important to determine whether these anomalies may indicate the effects of haar cooling.

A very generalised view of these data suggests a simple seasonal change without any minor irregularities attributable to the haar. This generalised view is obtained from Figure 7 in which isopleths are drawn for the data contained in Table 59. This diagram digests 96 different anomalies of mean maximum temperature each of which refers to a particular wind direction and month. These anomalies are arranged in a seven-fold classification in Figure 7.

Late winter is the period of high anomalies and February the peak month in this respect because it alone contains negative anomalies of over 6.0°F. Beyond this winter extreme period Figure 7 is typified by low negative anomalies with NW, N, NE, E and occasionally SE and W winds, together with low positive anomalies with S, SW, W and occasionally SE winds.

This general trend is attributable partly to air mass properties and partly to the seasonal changes in the frequencies of winds.

The air mass factor is dominated by the relative coldness of continental air masses in winter and their relative warmth in summer. Superimposed upon this is the relative coolness of N winds (Arctic air) at all times.



ANOMALIES OF MAXIMUM TEMPERATURE RELATED TO WIND DIRECTION, DURHAM OBS. 1937–'62

FIGURE 7

Monthly variations in wind frequencies can have an important effect upon the general trends in Figure 7 whenever a wind is relatively rare. This is because the maximum temperatures observed with such a wind will have had very little effect upon the monthly mean maximum temperature and so their mean maximum temperature may deviate strongly from this monthly mean. However this does not appear to be an important factor because NE and E winds are as rare in November and December as in February and because E and SE winds are rare at all times. Since a general view of these mean maximum temperatures shows that they are mainly controlled by the basic thermal properties of air masses it is necessary to consider whether any minor irregularities can be attributed to the haar.

Figure 5 contains the curves relating mean maximum temperature to wind direction in each month. These graphs have already been discussed individually. They clearly show the rapid increase in maximum temperatures with winds of the eastern group after March and the counter-clockwise movement of the wind direction associated with the highest maximum temperature during summer. There are no large troughs upon these curves which can be attributed to the haar cooling. Possibly the mean maximum temperatures observed with E winds are relatively low in April, May, June and August but depressions of equal magnitude occur with E winds in October and November.

Therefore a comparison of these means alone provides no positive evidence of the occurrence of the haar. It contains a negative suggestion that both the frequency and magnitude of the haar are very low but this must be treated with care because of two considerations. In late spring and early summer the continental air mass is often associated with warmth, stability and cloudlessness - the very condition which favour advective cooling over the North Sea. These conditions provoke occasional high maximum temperatures which may well offset the effects of the haar when means are calculated.

Additionally it must be remembered that both N and NE winds are very common in May and June and so even a moderately high frequency of haars in association with these winds may have little effect upon the mean maximum temperatures in Figure 5.

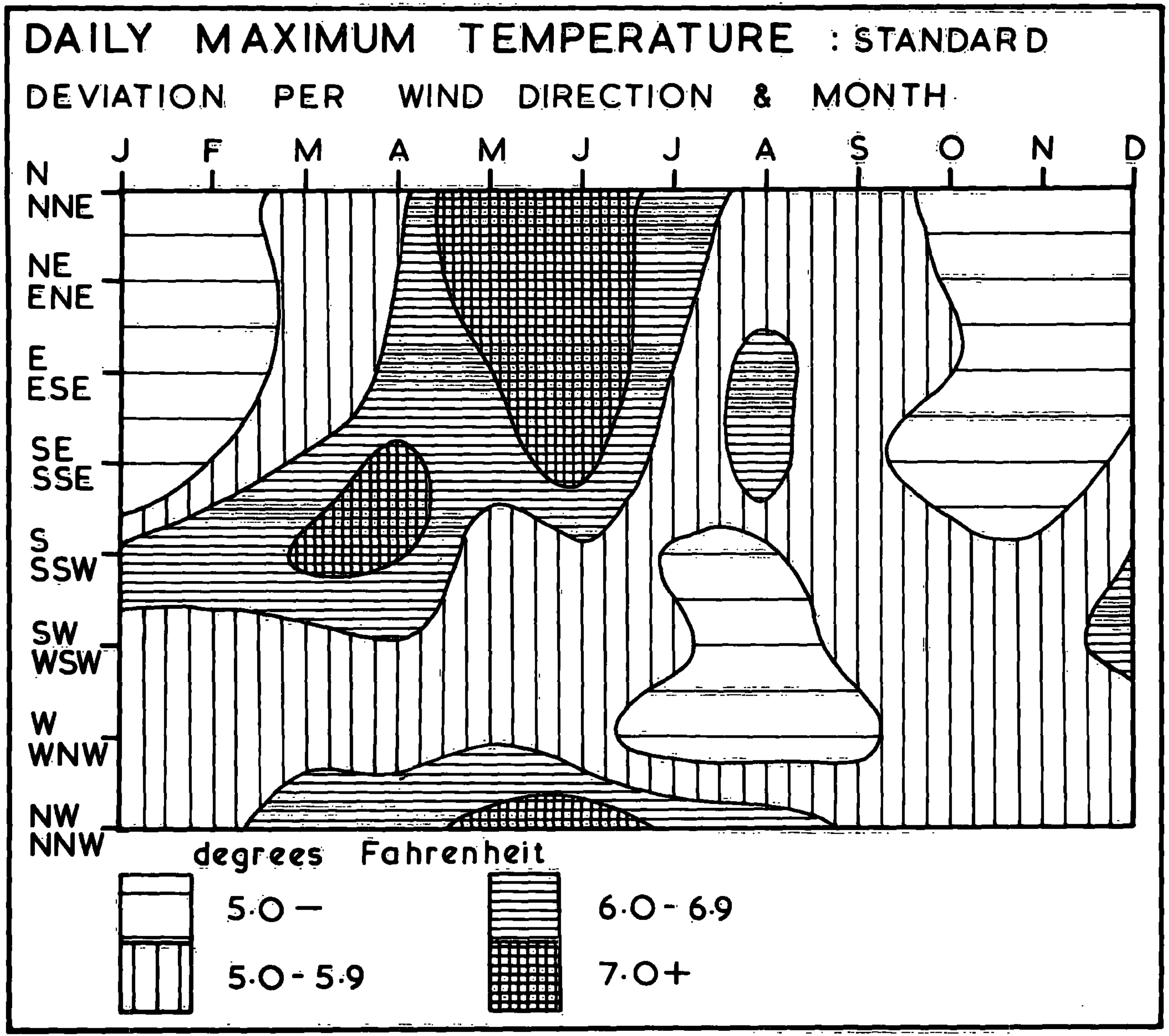
Clearly further discussion of the deviation of the data from these means is required to clarify the issues.

2. STANDARD DEVIATIONS OF MAXIMUM TEMPERATURE

There are large variations in the standard deviations of maximum temperature observed on days with different wind directions (Table 60). The highest standard deviation is 8.8°F and on nine other occasions it exceeds 7.0°F. The lowest standard deviation is 2.9°F and eleven others are less than 4.0°F.

A generalised view of the data (Figure 8) indicates that their variations are simple because the extreme values are usually limited to winds of the eastern group. These, together with NW winds, are associated with high standard deviations of maximum temperature in May and June and with low values from November to February. The winds of the western group, excluding NW winds, are associated with moderate standard deviations throughout the year though they do have a slight winter maximum and summer minimum in Figure 8.

The late spring and early summer period of high standard deviations with the winds of the eastern group is important to a study of the haar. Particularly interesting are the conditions in May and June because in these months the standard deviations are relatively high with N, NE, E and SE winds. April is definitely transitional in this respect. August is peculiar because it suffers a temporary return of high standard deviations with E and SE winds.



DAILY MAXIMUM TEMPERATURE : STANDARD DEVIATION PER WIND DIRECTION & MONTH

FIGURE 8

High standard deviations of maximum temperature will be encouraged by processes that favour both particularly high and particularly low maximum temperatures.

Particularly high maximum temperatures in late spring and early summer during days with continental air masses are favoured by the long daylight period at this time and by the frequent cloudlessness and stability of these air masses. Particularly low maximum temperatures under these circumstances will be encouraged by the haar.

In view of this dual control the results in Table 60 cannot be wholly attributed to the haar but they can be used as positive evidence suggesting its wind association and its seasonal distribution. May and June appear to be the period of peak haar frequency and August a month of greater haar frequency than July. These data suggest that the haar is relatively unimportant in April.

At this stage an examination of the skewness of the frequency distributions of these data is appropriate because it may suggest whether the high standard deviations of maximum temperature observed with winds of the eastern group are due to unusually common high or low maxima.

3. SKEWNESS OF MAXIMUM TEMPERATURE

The study of the skewness of the frequency distributions of daily maximum temperature has not, however, been of positive value in this analysis.

Fairly wide variations in skewness are present in Table 61 and the general form of these is shown in Figure 9. The basic relationships illustrated by Figure 9 are quite expected since they demonstrate that frequent relatively cold days are associated with continental influences in winter and with maritime influences in summer; whereas the reverse applies, in both cases, to relatively warm days. These comments are based on the assumption that a positive skewing (relatively large variations above the mean) is indicative of a high frequency of cold days and vice versa.

On this basis it is fair to expect positive skewing of maximum temperatures to occur in association with the haar. In Table 61 it is seen however that either negative skewing or symmetrical distributions occur with N and SE winds in April, E winds in May, and NE and E winds in June. Therefore these results are inconclusive.

However this is not a positive indication of the absence of a haar effect because it may merely demonstrate that the haar is unable to dominate the effects of occasional

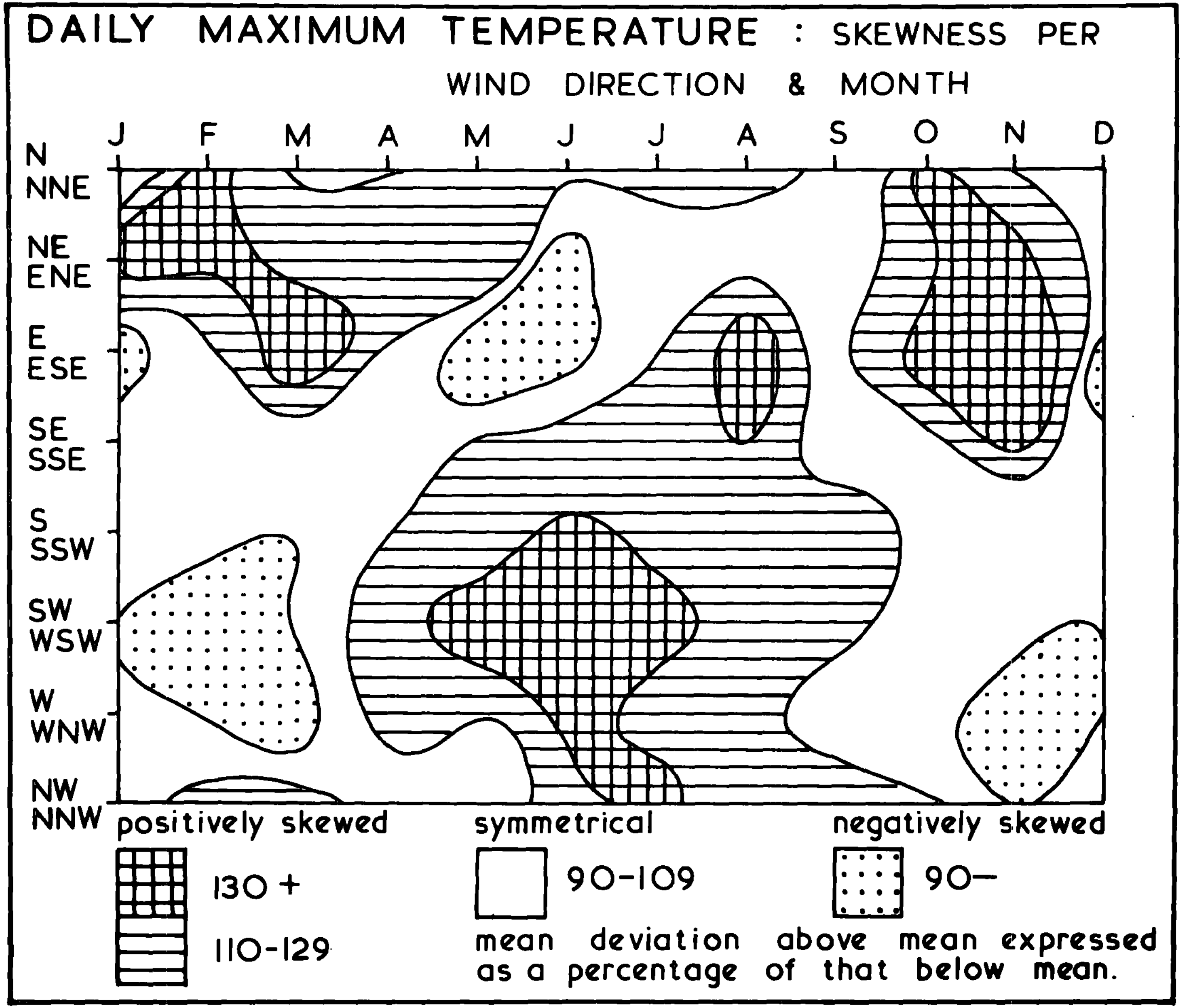

DAILY MAXIMUM TEMPERATURE : SKEWNESS PER WIND DIRECTION & MONTH
J
F
M
A
M
J
J
A
S
O
N
D
N
NNE
NE
ENE
E
ESE
SE
SSE
S
SSW
SW
WSW
W
WNW
NW
NNW
positively skewed
130 +
110-129
symmetrical
90-109
negatively skewed
90-
mean deviation above mean expressed as a percentage of that below mean.

FIGURE 9

very warm days occasionally observed with continental influences in late spring and early summer. This is suggested by the fact that negative skewing of maximum temperatures is observed with NE and E winds in June and with E winds in May. Additionally, this method of estimating skewness is effected considerably by the problem of small samples because the accidental irregularities which are apt to arise with these may seriously effect the ratio between two quantities. This may be the cause of the very wide variations in skewness (Figure 9) observed with E and SE winds throughout the year.

CHAPTER 4

SUNSHINE DURATION - THE DATA

The analysis of the record of sunshine duration at Durham Observatory is designed to describe any peculiarities in this record which can be attributed to the haar effect. These peculiarities are expected to include relatively low amounts of sunshine upon days with winds of the eastern group in late spring and early summer. If these effects are very pronounced they may depress the mean sunshine duration on such days so that relatively low mean durations of sunshine will occur on days with NE winds in May, SE winds in June etc. Weaker haar effects, while unable to depress the means in this way, may produce a relatively high frequency of sunless days with winds of the eastern group in late spring and early summer.

Initially it is tempting to expect that an analysis of the sunshine data similar to thatadopted in the previous discussion of maximum temperature will resolve this problem. Therefore the sunshine analysis commences with a classification of the daily observations of sunshine duration into 96 frequency distributions, exactly as in the previous chapter. Each of these refers to a particular month and wind direction. The frequency distributions are contained in Tables 62 to 73 and the data are plotted in a modified form in Figures 10a and 10b. These modifications are two-fold. Firstly the frequencies of days without sunshine are omitted since these are usually so great that they cannot be accommodated upon graphs of acceptable dimensions. Bilham[1], faced with a similar problem when preparing frequency distributions of sunshine data observed at Newquay, excluded all days with less than 0.1 hours from his graphs.

The second modification of the data in Figures 10a and 10b involves the use of two-hour groups. This is intended to improve the visual impression of the graph and in all calculations the original half-hour groups are used. The data contained in Tables 62 to 73 enable the calculation of the mean sunshine duration and the frequency of sunlessness on days with each wind direction in each month. As in the previous chapter these results will be discussed on a monthly basis (page 36).

Unfortunately the deductions which can be based upon these frequency distributions are severely limited because they take no account of the seasonal variations in

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[1] BILHAM, E.G. , Frequency distributions of sunshine at Newquay. Met.Mag., 70, 60, 1935

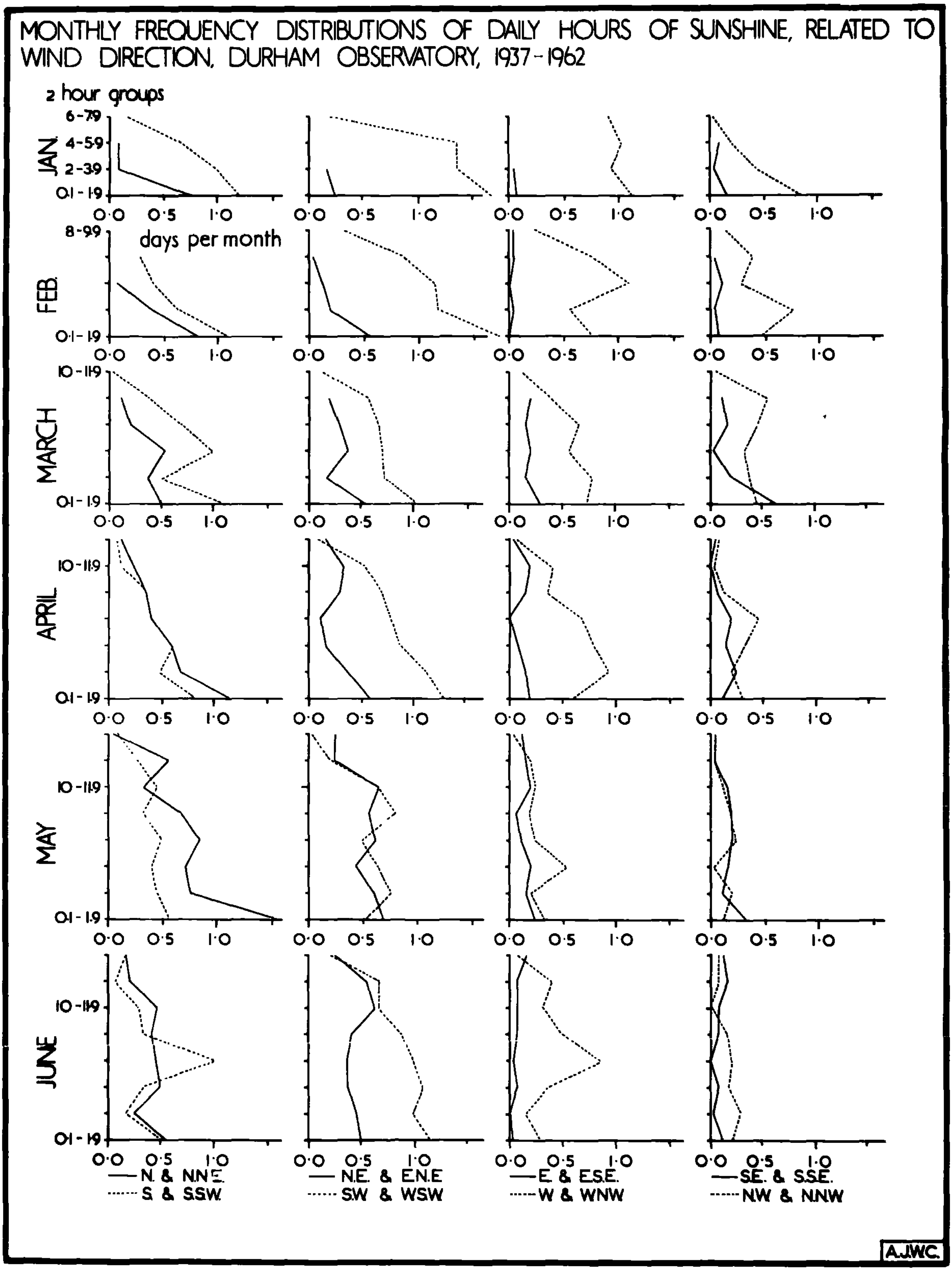

MONTHLY FREQUENCY DISTRIBUTIONS OF DAILY HOURS OF SUNSHINE, RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, 1937-1962

FIGURE 10a

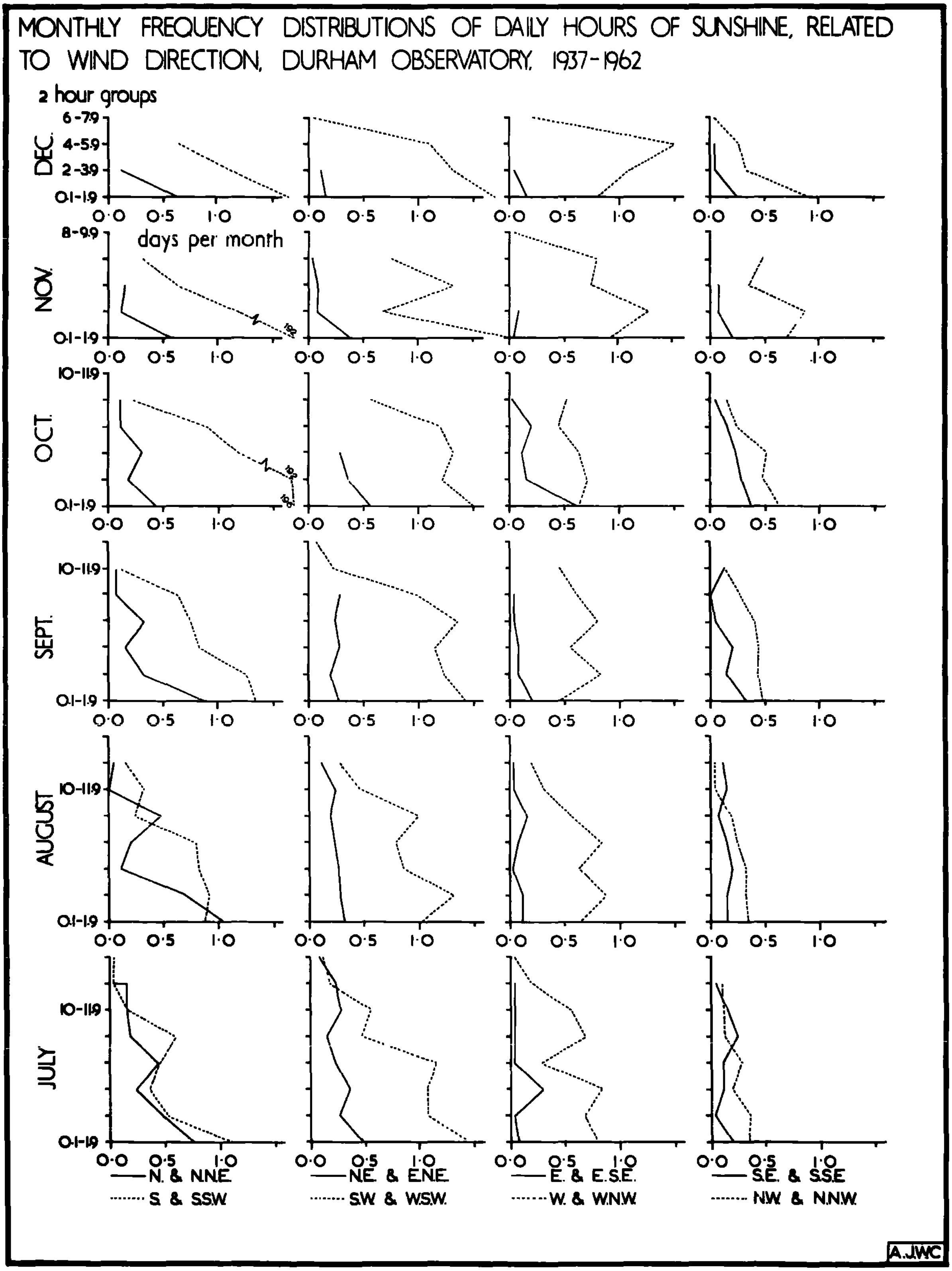

MONTHLY FREQUENCY DISTRIBUTIONS OF DAILY HOURS OF SUNSHINE, RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, 1937-1962

FIGURE 10b

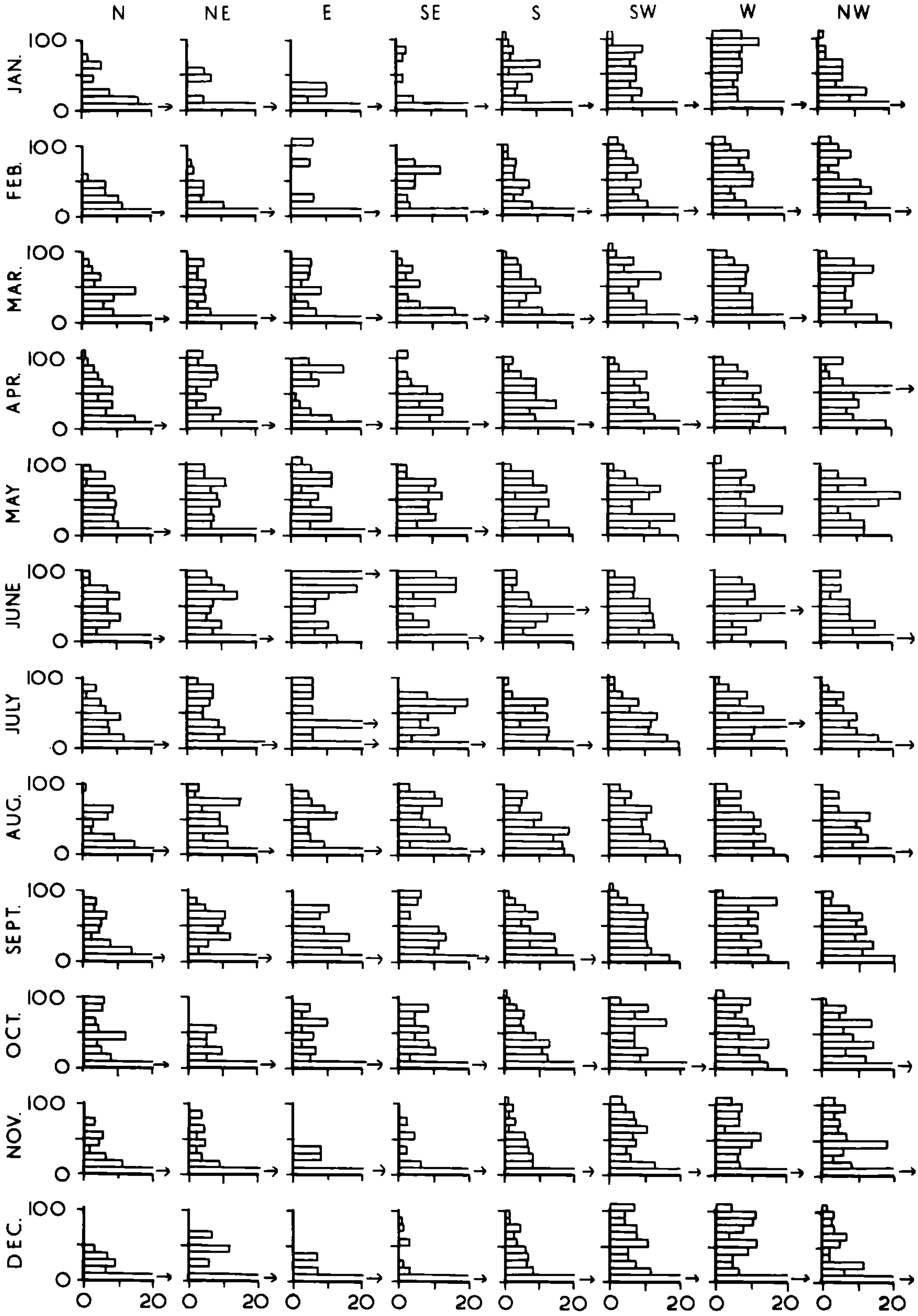
the possible duration of sunshine. These have no effect upon the comparison of the data observed on days with individual wind directions in each month but they prevent precise inter-monthly comparisons.

Therefore a second stage is added to this analysis and this involves the preparation of another set of 96 frequency distributions in which frequencies are expressed as percentages of the possible duration. These "adjusted" frequency distributions are contained in Tables 74 to 85 and Figure 11. The duration axes are subdivided into ten groups, including 0 to 9, 10 to 19 per cent of the possible etc. The frequencies are also plotted in percentages - the frequency of each ten per cent group being plotted as a percentage of the total number of observations in that frequency distribution. The contents of these adjusted frequency distributions will also be examined in the forthcoming monthly analysis.

However before these results are discussed it is necessary to describe the process by which the adjusted frequency distributions were prepared since this involved considerable modification of the original frequency distributions.

FIGURE 11

ADJUSTED FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, DURHAM OBSERVATORY, JULY 1937 – JUNE 1962



Vert. axis – percentage of possible. Horiz. axis – percentage of total observations per frequency distribution.

A. ADJUSTED FREQUENCY DISTRIBUTIONS

These were derived from the original frequency distributions of sunshine duration (Tables 62 to 73) in two stages. The first of these determines the value of the monthly mean daily possible duration of sunshine as measured by a Campbell-Stokes sunshine recorder. These values are the basis for the subsequent calculations of percentage durations. In the second stage the data, which were originally classified into half-hour groups are rearranged into ten groups each covering ten per cent of the duration axes.

1. MONTHLY MEAN DAILY POSSIBLE SUNSHINE DURATION

The actual monthly mean daily possible sunshine durations at latitude 55°N are given in Table 16.

TABLE 16. ACTUAL MONTHLY MEAN DAILY POSSIBLE SUNSHINE DURATIONS AT 55°N (hours)

Jan.	Feb.	Mar.	Apr.	May	June
7.8	9.6	11.8	14.0	16.1	17.2

July	Aug.	Sep.	Oct.	Nov.	Dec.
16.7	14.9	12.7	10.5	8.4	7.2

These are the mean periods during which the sun is above the horizon in each month. Unfortunately the Campbell-Stokes sunshine recorder is incapable of recording the weak sunshine which occurs when the elevation of the sun is very low. Therefore the observed possible duration is less than the actual duration and the data in Table 16 must be reduced accordingly.

Brooks[1] considers that this instrument only functions when the sun is elevated by at least 5° but the Meteorological Office[2] regards 3° as being the minimum solar elevation in this respect. The latter is adopted here since it avoids the very large corrections in winter which are demanded by the former.

The monthly mean daily durations of the period of solar elevations of less than 3° are given in Table 17.

TABLE 17. MONTHLY MEAN DAILY DURATIONS OF SOLAR ELEVATION OF LESS THAN 3° AT 55°N (hours)

Jan.	Feb.	Mar.	Apr.	May	June
1.2	0.9	0.9	0.9	0.9	1.0
July	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
0.9	0.9	0.8	1.0	1.1	1.3

Numerically these periods do not vary greatly but in percentage terms they necessitate a correction which is much greater in winter than in summer (Table 18) and this considerable seasonal change demonstrates the importance of this correction.

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[1] BROOKS, C.E.P., The relation between the duration of bright sunshine registered by a Campbell-Stokes sunshine recorder and the estimated amount of cloud. <u>Professional Notes</u>, 53, 1929

[2] ANON. <u>Handbook of Meteorological Instruments, Part 1.</u> pp. 308, 1956

TABLE 18. MONTHLY MEAN DAILY DURATION OF SOLAR ELEVATIONS OF LESS THAN 3° EXPRESSED AS A PERCENTAGE OF ACTUAL MONTHLY MEAN DAILY SUNSHINE DURATION AT 55°N

Jan.	Feb.	Mar.	Apr.	May	June
15.0	9.3	7.5	6.6	5.7	6.0

July	Aug.	Sept.	Oct.	Nov.	Dec.
6.0	6.0	6.6	9.3	12.9	18.0

Large corrections must be applied to the data because of the inadequacy of the Campbell-Stokes sunshine recorder. These corrections have been applied in Table 19.

TABLE 19. MONTHLY MEAN DAILY POSSIBLE SUNSHINE DURATION AS OBSERVED BY THE CAMPBELL-STOKES SUNSHINE RECORDER AT 55°N (hours)

Jan.	Feb.	Mar.	Apr.	May	June
6.6	8.7	10.9	13.1	15.2	16.2

July	Aug.	Sept.	Oct.	Nov.	Dec.
15.8	14.0	11.9	9.5	7.3	5.9

All expressions of sunshine duration in terms of percentages of the possible will be calculated using the data in Table 19.

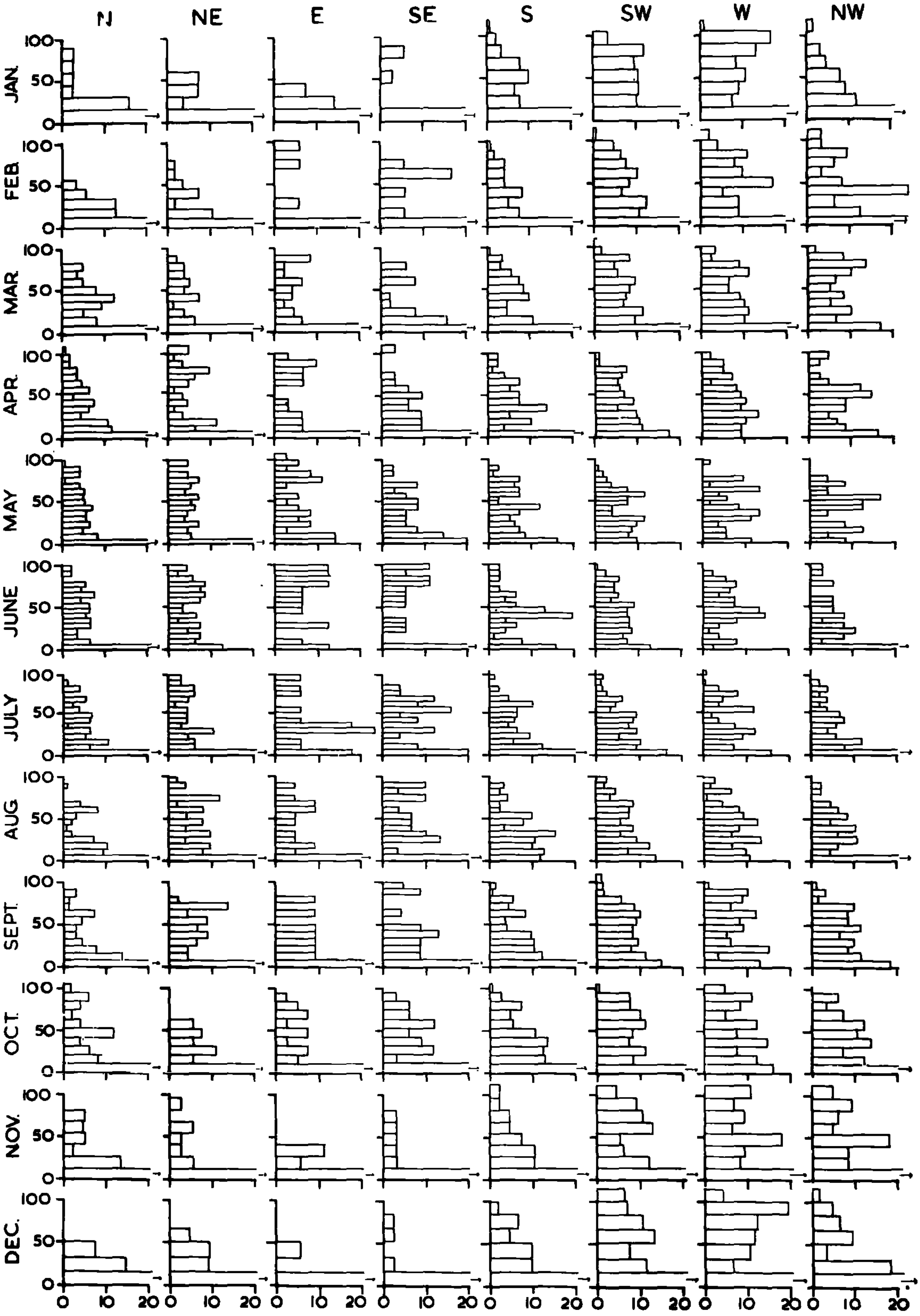
2. TEN PERCENT GROUPS

In the original frequency distributions (Tables 62 to 73) the data were arranged into half-hour groups commencing with 0.0 to 0.4 hours. Clearly these groups can be readily made to refer to percentages of the possible by simply expressing their limits as percentages of the maximum duration in each month. This is done in a simplified form in Figure 12 which combines the original half-hour groups to form one-hour groups for the purpose of this conversion. For example the lowest groups in Figure 12 include all durations between 0.0 and 0.9 hours. Unfortunately the product of this direct conversion is unsatisfactory since it does not allow a simple inter-monthly comparison.

The second stage in this modification of the original frequency distributions is designed to unify the individual graphs in Figure 12 by bringing the total number of groups in all cases to ten and, as far as possible, giving these identical limits. This arbitrary group size of ten per cent of the possible is considered to be sufficiently detailed to show significant sunshine properties while remaining simple. The large corrections which were occasionally required in the previous stage warrant only moderate detail in this case.

This consideration becomes particularly valid when it is seen that the ten percent groups cannot be assembled with equal accuracy. This is because in Figures 10a and 10b the data are prearranged upon the duration axes. These initial groups can be combined to achieve a ten per cent group but they cannot be subdivided if the limits of this

FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION – EXPRESSED AS PERCENTAGES OF THE POSSIBLE, DURHAM OBSERVATORY, JULY 1937 – JUNE 1962



Vert. axis – percentage of possible. Horiz. axis – perc. of total per freq. dist.

FIGURE 12

combination are not exactly those which are required by the adjusted frequency distribution.

In some cases these limits accidentally coincide exactly with those required by the ten per cent grouping and this conversion is achieved without any loss of accuracy. For example in May it is possible to calculate exactly the frequency of days having 0 to 9% of the possible sunshine duration because the half hourly group 1.0 to 1.4 hours accidentally coincides with an interval of 6.5 to 9.0% of the possible. Hence in May the required percentage is exactly equal to the sum of the frequencies of the half-hour groups 0.0 to 0.4, 0.5 to 0.9 and 1.0 to 1.4 hours.

In other cases this coincidence is lacking and the frequency of a particular ten per cent group can only be found with approximation. For example the third group is 20 to 29% but in June the most satisfactory combination of initial groups only gives a third group of 19 to 30%. This covers a range of 12% rather than 10% of the possible. In practically all of these cases this was corrected by simple proportions, i.e. in the present case the frequency of the third group in June was reduced by one sixth.

However it is unsatisfactory to adopt this simple proportional correction in the case of the lowest group

(0 to 9%) because the upper limit of this group occurs at a place where the frequency distribution curve is very steep and frequencies change rapidly.

When the calculated upper limit of this group deviates by only 1% from the required limit (i.e. it is 8% or 10%) the required correction in frequency was found graphically from the slope of the frequency distribution. If the calculated upper limit deviated by over 1% from the required upper limit there was no attempt to correct it and it was subsequently ignored. This occurred in January and December.

It may seem initially that these approximations are excessive but it must be emphasised that in the summer period from March to October only small corrections were required. This was because in these months the number of groups in the original frequency distributions (Figures 10a and 10b) were much higher than those required in the adjusted frequency distributions (in June there are thirty half-hour groups in the original frequency distributions.) Hence between March and October there was a close correspondence between the available group limits and those required for the construction of ten per cent groups.

CHAPTER 5

SUNSHINE DURATION - THE ANALYSIS

This chapter includes a description of the sunshine data on a monthly basis and a discussion of the implication of the results in terms of the haar effect. Three factors are examined in the monthly description. These include the mean daily sunshine duration, the frequency of sunshine amounts of less than ten per cent of the possible, and the frequency of sunless days. Each is examined in relation to the wind direction.

It will be observed that only a fragment of the information contained in the adjusted frequency distributions, that part of specific interest to the haar, is examined here. A thorough analysis of some implications of these adjusted frequency distributions forms the basis of Part 2 of this thesis.

A. MONTHLY ANALYSIS

1. JANUARY

TABLE 20. JANUARY: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	0.9	0.7	0.6	0.7	1.5	2.3	3.1	1.4
B.	61	79	79	84	57	36	25	51
C.	39	64	79	81	50	28	17	42

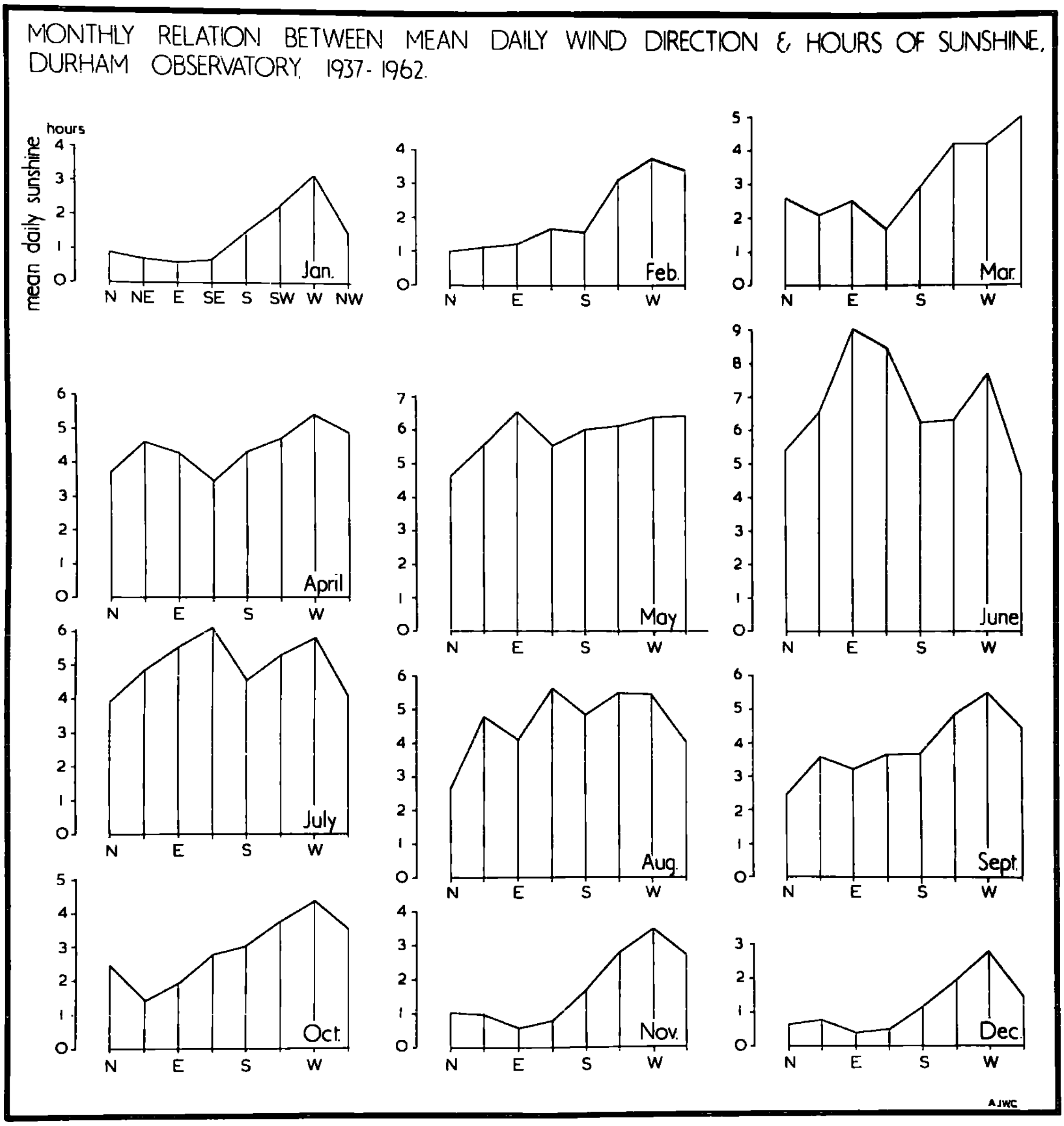
A= mean daily sunshine duration (hours)

B= percentage frequency of days with 0 to 7% of possible*

C= percentage frequency of sunless days

* relatively small interval because this cannot be corrected to normal group size (0 to 9%) - see page 70 .

In January mean daily sunshine durations are low but they vary greatly according to wind direction. A general contrast can be drawn between winds of the eastern group having mean durations of the order of 0.7 hours and those of the western group exceeding this by two to five times. However it is valid to contrast the relatively high mean durations observed with W and SW winds from the much lower values observed with all other winds. The total range between the maximum with W winds (3.1 hours) and the minimum with E winds (0.6 hours) is 2.5 hours. There is a smooth curve between these extremes (Figure 13).



MONTHLY RELATION BETWEEN MEAN DAILY WIND DIRECTION & HOURS OF SUNSHINE, DURHAM OBSERVATORY. 1937-1962.

FIGURE 13

Days with 0 to 7% of the possible sunshine vary greatly in their occurrence between high frequencies of about 80% of all days with NE, E and SE winds and a low of 25% of all days with W winds. Clearly the bulk of these days are sunless since there is a very close parallel between the values of B and C in Table 20. Sunlessness occurs upon 80% of all days with E and SE winds and on only 17% of all days with W winds (Figure 14).

2. FEBRUARY

TABLE 21. FEBRUARY: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	1.0	1.1	1.2	1.7	1.6	3.1	3.9	3.4
B.	63	70	80	64	61	31	21	22
C.	40	60	80	61	50	15	13	17

A= mean daily sunshine duration (hours)

B= percentage frequency of days with 0 to 9% of possible

C= percentage frequency of sunless days

Mean sunshine durations in February vary according to wind direction in basically the same way as in January. However in this case the mean duration observed with NW winds is comparable to those with W and SW winds. Between the maximum mean duration (3.9 hours observed with W winds)

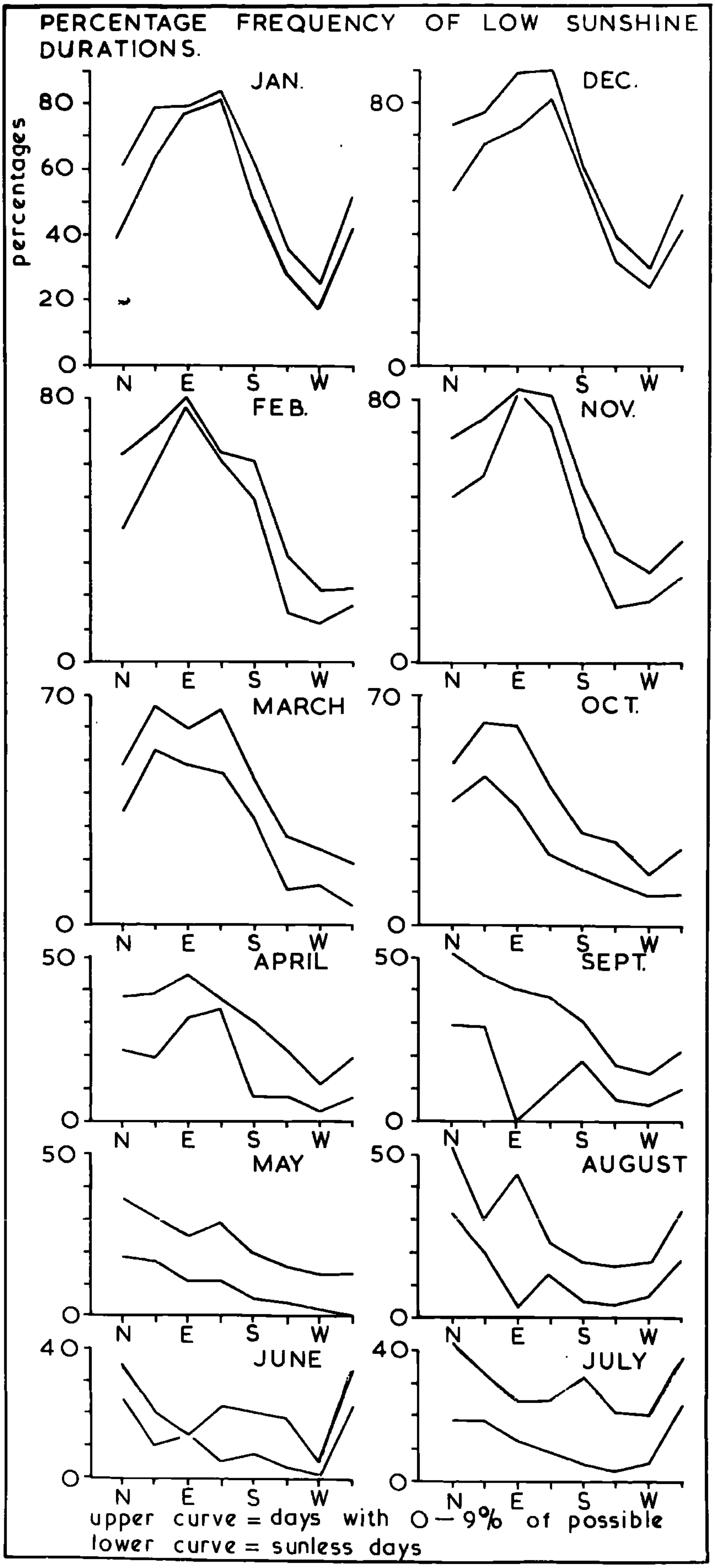

PERCENTAGE FREQUENCY OF LOW SUNSHINE DURATIONS.
percentages
JAN.
DEC.
FEB.
NOV.
MARCH
OCT.
APRIL
SEPT.
MAY
AUGUST
JUNE
JULY
80
60
40
20
0
70
50
40
N
E
S
W
upper curve = days with 0—9% of possible
lower curve = sunless days

FIG. 14

and the minimum (1.0 hour observed with N winds) there is a range of 2.9 hours and a fairly smooth curve.

Sunshine durations of 0 to 9% of the possible are much more common with winds of the eastern group than with those of the western group (excluding S winds). There is a sharp peak in the frequency of sunless days with E winds. The frequency of sunless days is less with N than with S winds.

3. MARCH

TABLE 22. MARCH: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A.	2.6	2.1	2.5	1.7	2.9	4.2	4.2	5.0
B.	49	66	59	65	45	27	23	18
C.	35	53	48	46	32	10	11	5

A= mean daily sunshine duration (hours)

B= percentage frequency of days with 0 to 9% of possible

C= percentage frequency of sunlessness

The general relationships between mean sunshine duration and wind direction which were observed in the previous months continue into March. The highest values are still observed with winds of the western group and these are generally twice as great as the means observed with winds of the eastern group. The total range between the maximum (5.0 hours with NW winds) and the minimum (1.7 hours with SE winds) is now 3.3 hours.

Days with NW winds are rarely associated with sunlessness or with 0 to 9% of the possible sunshine. Again, these are both much less common with SW, W and NW winds than with any other winds. Sunlessness occurs on about 50% of days with NE, E and SE winds. There is no sharp peak with E winds in the occurrence of either of these conditions.

4. APRIL

TABLE 23. APRIL: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	3.7	4.6	4.3	3.5	4.3	4.7	5.4	4.9
B	38	39	44	37	30	22	11	19
C	21	20	32	34	7	7	3	7

A= mean daily sunshine duration (hours)

B= percentage frequency of days with 0 to 9% of possible

C= percentage frequency of sunless days

By April there is a basic alteration in the relation between mean daily sunshine duration and wind direction (Figure 13). Peak durations are still observed with W winds but there is now very little contrast between winds of the eastern and western groups. Hence the total range beween the maximum (5.4 hours with W winds) and the minimum 3.5 hours with SE winds) is now only 1.9 hours.

However both sunless days and days with 0 to 9% f the possible sunshine duration are still much more common two or three times as frequent) with winds of the eastern roup than with those of the western group. Sunlessness is articularly interesting because of its peak with E and SE inds. With both of these it occurs upon about one third f all days whereas with both N and NE winds this frequency alls to about one fifth of all days.

. MAY

ABLE 24. MAY: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

N	NE	E	SE	S	SW	W	NW
4.6	5.6	6.6	5.5	6.0	6.1	6.4	6.4
36	31	25	29	19	15	13	13
18	17	11	11	5	4	2	0

= mean daily sunshine duration (hours)

= percentage frequency of days with 0 to 9% of possible

= percentage frequency of sunless days

The relative increase in mean daily sunshine duration ith winds of the eastern group continues into May. Hence n May the highest mean (6.6 hours) is observed with E winds and the range of variation between this and the lowest mean 4.6 hours with N winds) is only 2.0 hours. Generally however the means observed with winds of the eastern group are rough-y one hour lower than those observed with winds of the estern group and there is a pronounced trough with N winds.

Despite this the winds of the eastern group continue o suffer from between two and three times as many sunless ays and days with 0 to 9% of the possible sunshine dura-ion than those of the western group. May is the first onth in which N winds have the highest frequency of both f these conditions and it is also the first month in which unless days do not constitute over half of all days with ess than ten per cent of the possible sunshine.

. JUNE

ABLE 25. JUNE: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

N	NE	E	SE	S	SW	W	NW
5.4	6.6	9.1	8.4	6.2	6.3	7.7	4.6
35	22	13	22	20	18	5	35
24	10	13	5	8	3	1	22

= mean daily sunshine duration (hours)

= percentage frequency of days with 0 to 9% of possible

= percentage frequency of sunless days

There is a large range (4.5 hours) in mean daily unshine duration in June because very high values are ob-erved with E and SE winds. This is the culmination of the elative increase, noted in April and May, in this quantity ith winds of the eastern group. The means observed with N nd NE winds are considerably below those observed with E nd SE winds.

By June the occurrences of both sunless days and ays with 0 to 9% of the possible sunshine have generally allen to very low values though they are both still most ommon with winds of the eastern group. N and NW winds both uffer considerable excesses of both of these conditions.

. JULY

ABLE 26. JULY: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

N	NE	E	SE	S	SW	W	NW
3.9	4.9	5.5	6.1	4.5	5.3	5.8	4.1
42	33	24	24	31	20	20	38
18	18	11	8	5	3	5	23

= mean daily sunshine duration (hours)

= percentage frequency of days with 0 to 9% of possible

= percentage frequency of sunless days

The variations of mean sunshine duration in July re basically similar to those observed in the previous hree months, though the very high values observed with E nd SE winds in June are now absent. There is no clear ontrast in this respect between winds of the eastern and hose of the western groups. The total range, between the maximum (6.1 hours observed with SE winds) and the minimum (3.9 hours observed with N winds) is only 2.2 hours. As in June the mean sunshine durations observed with S winds form a secondary trough.

The distribution of days with 0 to 9% of the possible sunshine duration continues a pattern which was first observed in June - relative equality between the values observed with winds of the eastern and those of the western groups. Outstanding features of these data are their high values with winds from the north (NW, N and NE) and the secondary peak with S winds. Sunlessness is also basically associated with winds from the north but it is also rather more frequent with E and SE winds than with S, SW and W winds.

8. AUGUST

TABLE 27. AUGUST: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	2.7	4.8	4.1	5.6	4.8	5.5	5.5	4.1
B	52	30	43	22	17	16	17	33
C	31	19	3	13	5	4	6	17

A= mean daily sunshine duration (hours)

B= percentage frequency of days with 0 to 9% of possible

C= percentage frequency of sunless days

In August mean sunshine durations vary irregularly according to wind direction, and this is especially true among winds of the eastern group. The maximum value (5.6 hours with SE winds) is 2.9 hours greater than the minimum(2.7 hours with N winds). Despite the irregularities the means observed with the winds of the western group are now greater than those observed with the winds of the eastern group and this represents the beginnings of a return to the mid winter conditions.

The variations of days with 0 to 9% of the possible sunshine and of sunless days also suggest this return to winter conditions because in both cases relatively high frequencies are observed with winds of the eastern group. However the outstanding features of these data are the remarkably high values observed with N winds. In August, days with 0 to 9% of the possible sunshine duration amount to over 50%, and sunless days amount to over 30% of all days with N winds. Frequencies of this magnitude have not been observed under any circumstance since March.

9. SEPTEMBER

TABLE 28. SEPTEMBER: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	2.5	3.5	3.2	3.6	3.7	4.8	5.5	4.4
B	51	44	40	38	31	17	15	21
C	29	29	-	9	18	6	5	10

A= mean sunshine duration (hours)

B= percentage frequency of days with 0 to 9%

C= percentage frequency of sunless days

In September the return to the winter pattern of mean sunshine duration is well established because means observed with winds of the western group considerably exceed those observed with winds of the eastern group. As in the winter months the highest mean now occurs with W winds (5.5 hours) and that observed with S winds is relatively low. The range between the highest and lowest (2.5 hours with N winds) is 3.0 hours.

Days with 0 to 9% of the possible sunshine are again relatively common with winds of the eastern group and are particularly common with N winds. S winds again have a relatively high frequency of these days plus a secondary peak of sunless days. The latter are surprisingly rare with SE winds and they are not observed with E winds. Substantial minima in the frequency of sunless days occur with N and NE winds.

10. OCTOBER

TABLE 29. OCTOBER: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	2.5	1.4	1.9	2.8	3.0	3.7	4.4	3.5
B	49	62	61	42	28	25	15	23
C	38	45	36	21	17	13	9	9

A= mean sunshine duration (hours)

B= percentage frequency of days with 0 to 9% of possible

C= percentage frequency of sunless days

There is no major change in the association between mean sunshine duration and wind direction from September to October. However for the first time since April the lowest mean occurs with NE winds, rather than N or NW winds. Also in October a very smooth curve is established between this minimum (1.4 hours) and the maximum (4.4 hours with W winds). The total range is 3.0 hours.

Equally smooth are the variations in the frequency of days with 0 to 9% of the possible sunshine and of sunless days. In both cases the peaks of these curves occur with NE or E winds, again an implication of a return to winter conditions. In the cases of winds of the eastern group the majority of days with 0 to 9% of the possible sunshine are sunless.

11. NOVEMBER

TABLE 30. NOVEMBER: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	1.0	1.0	0.6	0.8	1.7	2.8	3.5	2.7
B	68	74	83	81	53	33	27	37
C	50	56	83	72	38	17	18	26

A= mean sunshine duration (hours)

B= percentage frequency of days with 0 to 9% of possible

C= percentage frequency of sunlessness

November again displays a typical winter variation of mean sunshine duration according to wind direction. The highest value (3.5 hours) is with W winds, the lowest (0.6 hours) is with E winds and between these there is a very smooth curve of amplitude 2.9 hours. In all cases the means observed with winds of the eastern group are substantially below those observed with winds of the western group.

Similarly the variations within lines B and C in Table 30 conform to the extreme winter pattern. Days with 0 to 9% of the possible and sunless days are extremely common with winds of the eastern group and the peak occurs with E winds.

12. DECEMBER

TABLE 31. DECEMBER: SUNSHINE DURATION RELATED TO WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
A	0.6	0.7	0.4	0.5	1.1	1.9	2.8	1.5
B	73	77	89	90	60	39	30	52
C	53	68	72	81	56	32	24	41

A= mean sunshine duration (hours)

B= percentage frequency of days with 0 to 7%* of possible

C= percentage frequency of sunless days

*relatively small interval because this group cannot be corrected to normal group size (0 to 9%) - see page 70

The lowest mean daily sunshine duration (0.4 hours with E winds) observed under any circumstance occurs, as expected, in December. This is 2.4 hours less than the highest mean (2.8 hours with W winds) and between these extremes there is a very smooth curve possessing a broad trough among winds of the eastern group and a sharp peak with W winds.

Similarly the highest frequency of days with 0 to 7% of the possible occurs in December (90% with SE winds). As in January and February a large proportion of these days with 0 to 7% of the possible consists of sunless days.

B. DISCUSSION

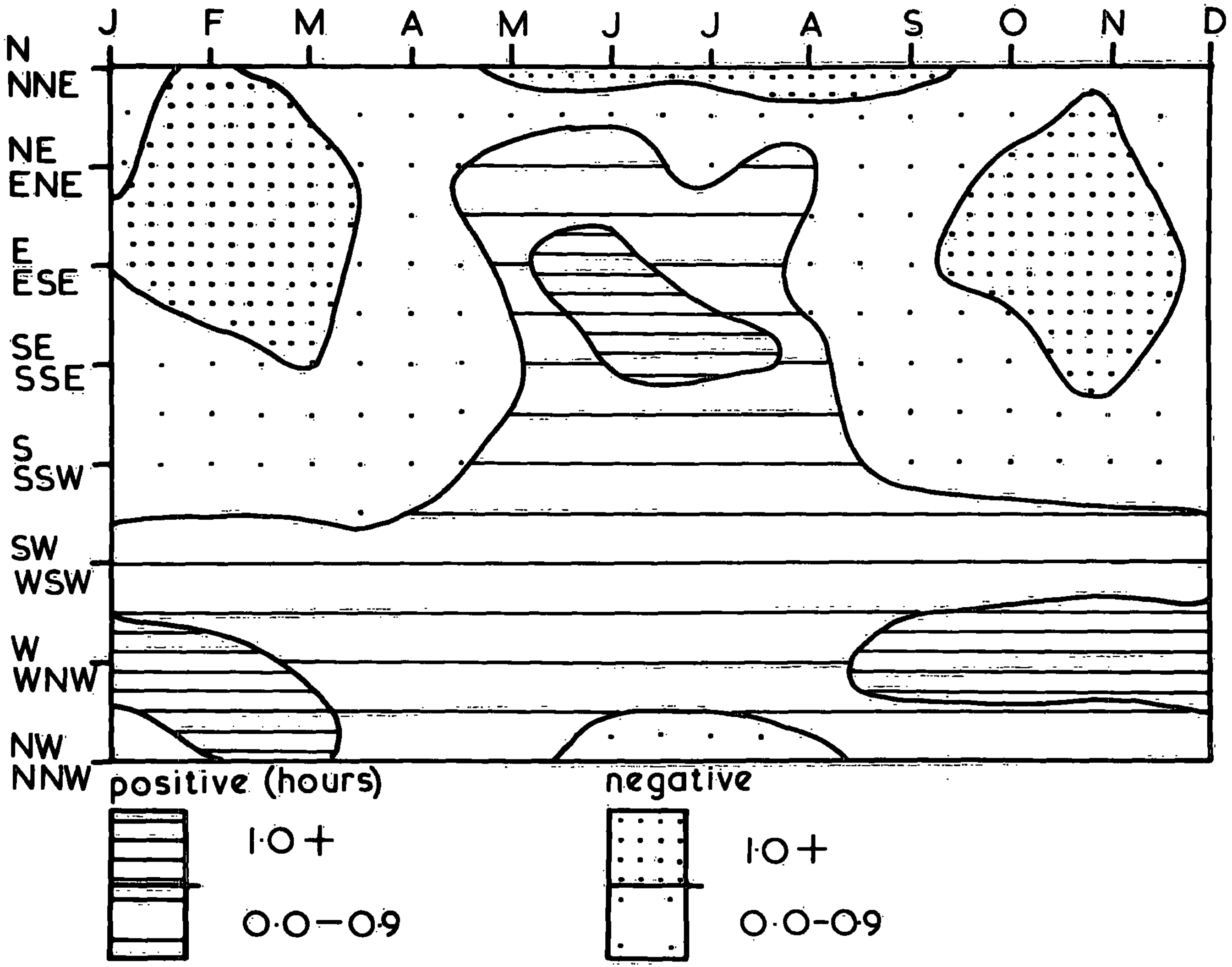
1. MEAN SUNSHINE DURATION

The previous analysis has shown that mean daily sunshine durations can vary widely according to wind direction in individual months. This discussion is designed to show whether any of these variations are attributable to the haar effect.

A generalised view of these variations is provided in Figure 15 in which the anomalies of sunshine duration are shown collectively. These anomalies have been calculated in exactly the same way as in the discussion of maximum temperatures (page 54). Thus the anomaly observed with N winds in January is -0.7 hours since their mean sunshine duration of 0.9 hours compares with a January mean sunshine duration of 1.6 hours. The anomalies are listed in Table 87 and for the construction of Figure 15 they have been arranged into four groups which are distinguished by isopleths.

Figure 15 shows that the variations of mean daily sunshine duration according to wind direction are fairly simple. During a short summer period from May to August

ANOMALIES OF MEAN SUNSHINE DURATION, PER WIND DIRECTION



the winds of the eastern group usually have pronounced positive anomalies (over 1.0 hours) and those of the western group have weak positive anomalies (less than 1.0 hours). Excluded from this generalisation are the anomalies observed with N and NW winds. These are negative, and pronounced in the case of N winds.

Over a long winter period from September to April the distribution of anomalies is quite different. Positive anomalies are again observed with winds of the western group, and in the case of W winds these are now pronounced. Negative anomalies are observed with winds of the eastern group, plus S winds. Between October and March these negative anomalies, particularly those with E and NE winds, are often pronounced.

The basic variations shown in Figure 15 are readily explained since they are due mainly to the seasonal variations in the contrast between general maritime and continental influences. However, as in the case of maximum temperature anomalies (page 56) the seasonal changes in the relative frequencies of the wind directions have also effected this pattern of anomalies. Thus the anomalies observed with winds of the eastern group swing between wide extremes (-1.6 hours with NE winds in October, to +3.2

hours with E winds in June) because of two factors.

Of major importance is the great seasonal contrast in the character of continental air masses. But of considerable secondary importance is the relative infrequency of the winds of the eastern group at most times of the year. This determines that days with winds of the eastern group have relatively little effect upon the monthly mean sunshine durations.

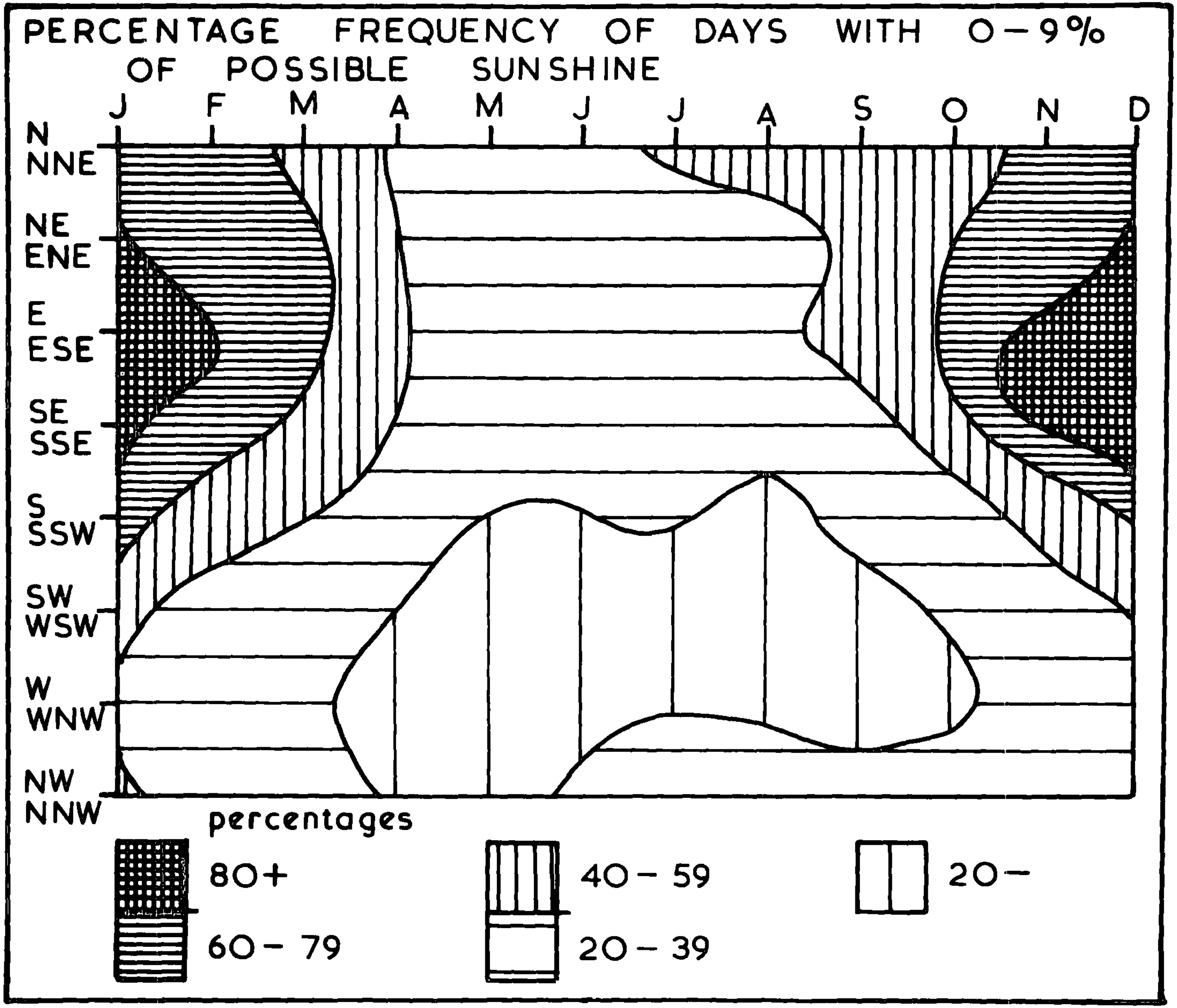
Neither the general variations in mean daily sunshine duration shown in Figure 15, nor the actual monthly curves in Figure 13 possess any irregularities which are attributable to the haar effect. Throughout the summer period relatively low mean sunshine durations are associated with N winds but this is readily explainable in terms of the instability of Arctic air masses and the release of this instability along the elevated and, in summer, warm east coast surfaces.

This failure of the haar to dominate the mean sunshine durations is in accordance with the results observed in the study of mean daily maximum temperatures. During this previous analysis it was observed that there are, however, some peculiarities in the forms of the maximum temperature frequency distributions which may be due to the haar. A discussion of the frequencies of sunless days and of days with 0 to 9% of the possible sunshine duration should indicate whether there are any similar peculiarities within the frequency distributions of sunshine duration.

2. SUNLESS DAYS; DAYS WITH 0 TO 9% OF THE POSSIBLE SUNSHINE DURATION

The monthly description has shown that there are very wide variations in the percentage frequency of sunless days and days with 0 to 9% of the possible sunshine duration. In Figures 16 and 17 isopleths of percentage frequencies (Tables 88 and 89) give impressions of the magnitude of these changes plus their general simplicity. Attention should be drawn to the fact that in Figure 16 the December and January frequencies refer to sunshine amounts of 0 to 7% of the possible (see page 70).Figure 14 contains the actual monthly curves of each of these groups of data.

Figures 16 and 17 show clearly that the frequencies of both of these quantities are basically governed by the seasonal variations in the contrast between maritime and continental influences. This accounts for their very high frequencies in winter in association with winds of the eastern group.


PERCENTAGE FREQUENCY OF DAYS WITH 0-9% OF POSSIBLE SUNSHINE
J
F
M
A
M
J
J
A
S
O
N
D
N
NNE
NE
ENE
E
ESE
SE
SSE
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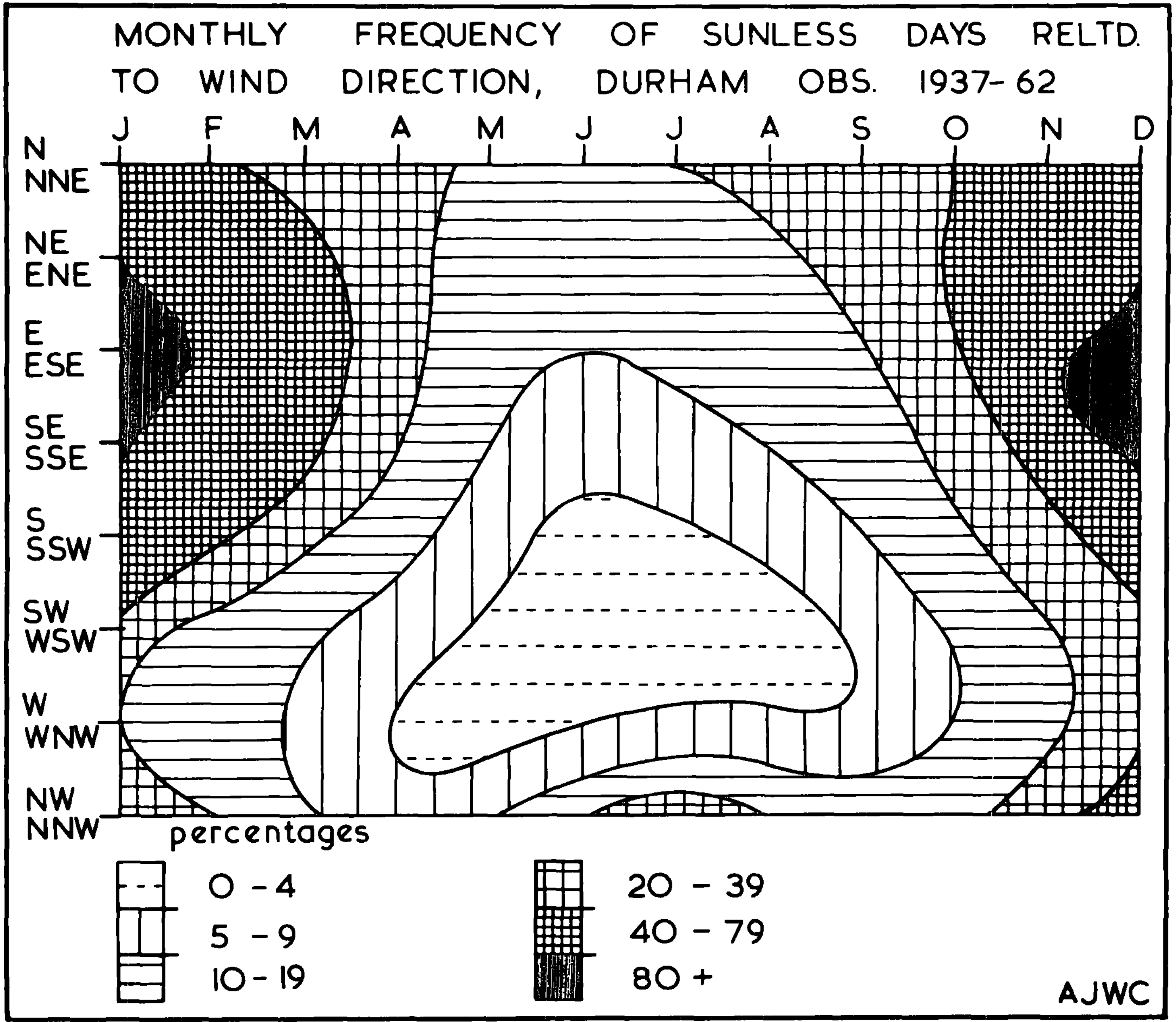
percentages
80+
60 - 79
40 - 59
20 - 39
20-


MONTHLY FREQUENCY OF SUNLESS DAYS RELTD. TO WIND DIRECTION, DURHAM OBS. 1937-62

However summer conditions are extremely interesting because they conflict with this observation. In the previous discussion of mean sunshine duration it was found that continental warmth and dryness is sufficient to provoke relatively high means between May and August. Despite this the highest frequencies of sunless days and of days with 0 to 9% of the possible sunshine in summer occur with winds of the eastern group. A general estimate of the magnitude of this contrast is provided by the data in Table 32.

TABLE 32. PERCENTAGE FREQUENCIES OF SUNLESS DAYS BETWEEN MAY AND AUGUST IN ASSOCIATION WITH WINDS OF EASTERN AND WESTERN GROUPS RESPECTIVELY, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	May	June	July	August
Eastern	17	16	16	23
Western	4	6	7	6

Of course the contrasts between these values are greater in other months but those in Table 32 are important because they occur during the time of the year when the continental influences are such as to provoke higher mean sunshine durations than the maritime influences.

These peculiarities are likely to be partly due to the haar effect.

CHAPTER 6

CRITICISM OF METHODS

The previous analyses have shown that there are some minor properties of the frequency distributions of daily maximum temperature and sunshine duration which may be attributed to the effects of the haar.

Standard deviations of maximum temperature upon days with winds of the eastern group in April, May and June exceed those observed under any other circumstance. Between May and August the percentage frequencies of sunless days are considerably greater with winds of the eastern group than with those of the western group. These observations are functions of wide varieties of controls but they may be partially attributed to the effects of the haar.

Despite these observations the basic implication of these analyses is that the climatic effects of the haar are very weak. Apparently the haar fails to depress the mean maximum temperatures and sunshine durations of days with winds of the eastern group in April, May and June. This is surprising because of its profound effects upon weather.

This chapter will discuss the failure of the analyses to demonstrate a strong climatic effect of the haar. It will be especially concerned with the possibility that this failure is due to inadequacies in the methods which have been used.

A. THE METHODS; POSSIBLE INADEQUACIES

Climatological analyses may suffer from two basic sources of error.

The first occurs at the source of data and is instrumental. It has frequently been shown that faulty design, exposure or operation of instruments have been responsible for errors in climatological analyses. Two considerations suggest that this is not operative in the present case. The first involves the fact that the failure to demonstrate a strong haar effect is common to both the maximum temperature and the sunshine duration analyses. In both cases minor peculiarities of comparable magnitude are attributable to the haar. Secondly it must be stressed that the effects of the haar upon daily weather are very pronounced. Reductions of daily maximum temperature by up to 10°F or 20°F and reductions of sunshine hours by up to 10 hours or 15 hours are easily detected and will not be obscured by minor instrumental errors.

A second basic source of error in climatological analyses is their tendency to be extremely generalised. This generalisation is caused by the need to examine extremely complex phenomena using the simple data obtained by a normal climatological station. As in the present case the basic generalisations are usually threefold. Firstly the observations from a point upon the surface are taken to apply to a wider area. Secondly seasonal variations are described in terms of the properties of the calendar months. Thirdly the annual changes are often ignored and the data drawn from a large number of years are examined collectively.

Clearly this problem of overgeneralisation may well apply in the present case. The period of peak haar frequency may be undetectable by a seasonal study based on the calendar month. Furthermore, the phenomenon is particularly common in some years and almost absent in others. A 25-year grouping of the data may obliterate the effects of those years with a high haar frequency. These two possible sources of error will now be examined individually.

. SEASONAL CHANGES IN HAAR FREQUENCY

In this case the problem is that the monthly interval may be too crude to detect periods of peak haar frequency of short duration. Clearly this can be verified by employing a much more detailed subdivision of the year and in the present analysis an arbitrary subdivision of the year into 73 units each covering five days is adopted. This is chosen because it eliminates the wide accidental variations which are introduced when days are studied individually while illuminating seasonal changes not apparent in the monthly analyses. The first of the 5-day groups extends from January 1st to January 5th. The remaining groups follow on from this ignoring the limits of the calendar months. For example in April, May and June the 5-day groups are as follows:

5-day group	April	May	June
1	31 Mar.-4 Apr.	30 Apr.-4 May	30 May-3 June
2	5 - 9	5 - 9	4 - 8
3	10 - 14	10 - 14	9 - 13
4	15 - 19	15 - 19	14 - 18
5	20 - 24	20 - 24	19 - 23
6	25 - 29	25 - 29	24 - 28

Mean maximum temperatures calculated on the basis of these 5-day groups follow an expected pattern (Figure 18). There is a regular seasonal change though minor irregularities occur upon the resultant curve.

One of these irregularities occurs at the end of April and beginning of May. Figure 18 shows that the

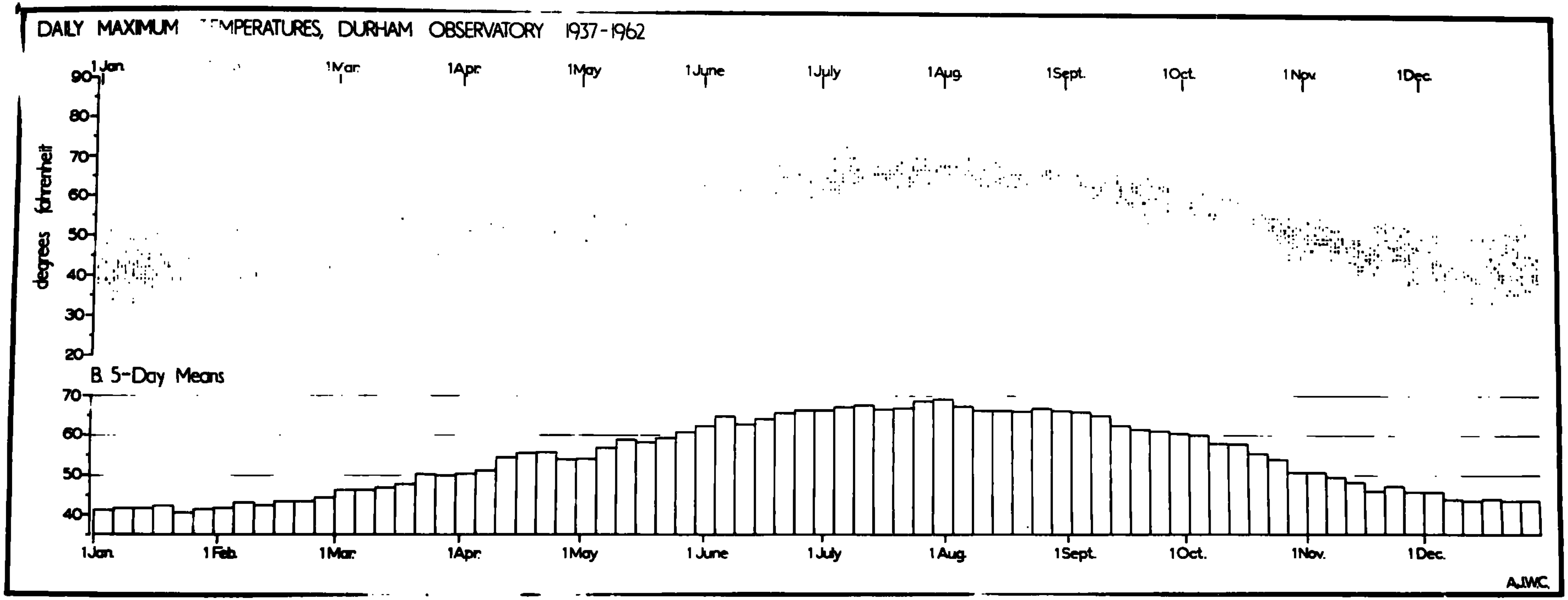

DAILY MAXIMUM TEMPERATURES, DURHAM OBSERVATORY 1937-1962
1 Jan.
1 Mar.
1 Apr.
1 May
1 June
1 July
1 Aug.
1 Sept.
1 Oct.
1 Nov.
1 Dec.
90
80
70
60
50
40
30
20
degrees fahrenheit
B. 5-Day Means
70
60
50
40
1 Jan.
1 Feb.
1 Mar.
1 Apr.
1 May
1 June
1 July
1 Aug.
1 Sept.
1 Oct.
1 Nov.
1 Dec.
A.J.W.C.

FIGURE 18

mean daily maximum temperatures of the last 5-day group in April (April 25th to 29th) and the first 5-day group of May (30th April to 4th May) are slightly depressed. Since this may be due to the effects of the haar the maximum temperatures within each of these groups are further differentiated on the basis of wind direction.

The daily maximum temperatures observed with the winds of the eastern group during each of the 5-day groups in April, May and June are shown in Figure 19. Additionally this figure contains curves showing the mean daily maximum temperature for each 5-day group. The thick curves are identical since they connect 5-day means calculated for all days irrespective of wind direction. The thin curves connect 5-day means calculated for individual wind directions and these are only drawn for N and NE winds. Figure 19 appears to confirm the suggestion that there is a peak haar period during the last 5-day group in April and the first 5-day group in May because it demonstrates that this period is relatively cold in the case of N, NE, E and SE winds. This is especially pronounced with NE winds (see Table 33).

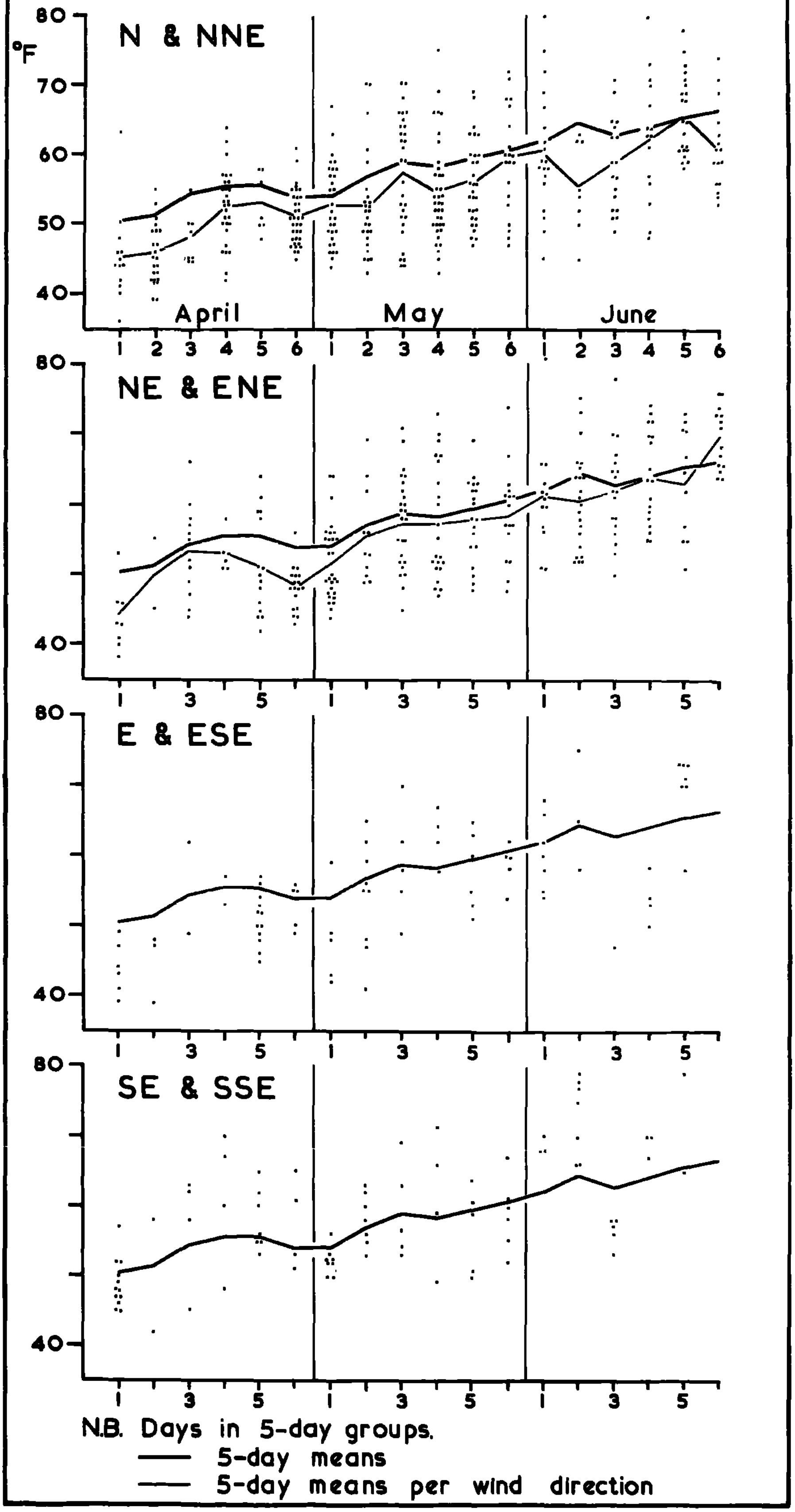


FIG
19

MAXIMUM TEMPERATURES IN APRIL, MAY & JUNE RELATED TO WIND DIRECTION, DURHAM 1938-62

TABLE 33. DAYS WITH N AND NE WINDS: MEAN DAILY MAXIMUM TEMPERATURES PER 5-DAY GROUP, APRIL TO JUNE, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	April						May		
	Group						Group		
	1	2	3	4	5	6	1	2	3
A -	45.1	45.7	48.0	52.5	53.1	51.0	52.8	52.6	57.4
B -	44.5	50.0	53.3	53.0	51.3	48.1	51.9	55.6	57.6

	May			June					
	Group			Group					
	4	5	6	1	2	3	4	5	6
A -	54.5	56.0	59.3	60.6	55.4	58.8	62.6	65.7	61.1
B -	57.4	58.0	58.6	61.4	60.4	62.0	64.1	63.5	69.6

A = days with N winds

B = days with NE winds

The mean maximum temperature observed on the 18 days with NE winds between the 25th and the 29th of April is 5.2°F lower than that observed on the 12 days with NE winds between the 10th and 14th of April.

This contrast suggests a period of peak haar frequency in late April. However, this can only be confirmed by comparing the Durham data with similar data from other British stations. A late April cold spell attributable to the haar should not be observed at central or western stations.

2. ANNUAL CHANGES IN HAAR FREQUENCY

The second major problem regarding these analyses involves the annual variations in haar frequency. If these are excessive there is a possibility of conditions obtaining during non-haar years dominating those obtaining during years with peak haar frequencies. Clearly this could explain the failure of the present analysis to detect strong haar effects.

Unfortunately it is impossible to estimate the actual annual haar frequencies since the phenomenon cannot be defined precisely. However it is desirable to have some quantitative estimate of its probable frequency and this is obtained by counting the occurrences of "cold, cloudy, easterly" weather in April, May and June during each year of the period of analysis. This weather is defined as follows.

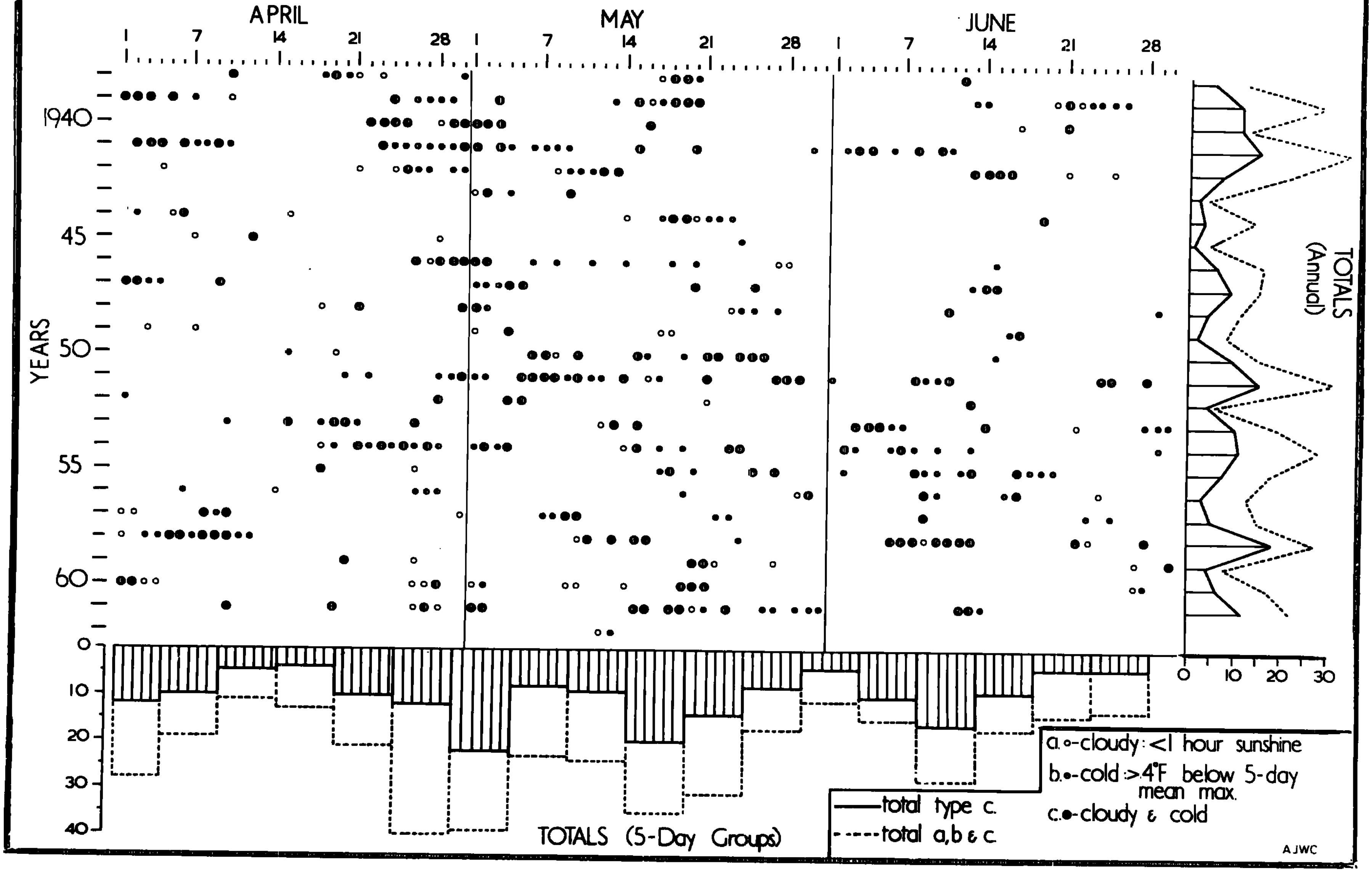
"Cold" days have actual maximum temperatures which are at least 4°F colder than the 5-day mean maximum temperature (page 93) for the period during which that day occurs. "Cloudy" days have less than 1.0 hours of sunshine. "Easterly" weather occurs on days with winds of the eastern group. The limit chosen for cold days may appear high but this produces a mean of seven such days in April, May and June together. This is only slightly higher than Manley's estimate of mean haar frequency during this period (page 10).

The frequency of cold, cloudy, easterly weather in April, May and June is shown in Figure 20. Also shown in this diagram are the frequencies of days with winds of the eastern group which are either "cold" or "cloudy" but which did not have both of these properties. Figure 20 shows that there are wide annual variations in the frequency of these conditions during the three-month period.

The frequency of cold, cloudy, easterly weather n April, May and June exceeded five occasions in 16 years, t exceeded ten occasions in seven years, and it exceeded 5 occasions in two years. The highest frequency of this ype of weather was in 1958 when it occurred on 18 days in pril, May and June.

These two sample studies show that, while the faiure of the previous analyses to demonstrate a strong haar ffect upon climate may be due to its actual infrequency, his may also be due to over-generalisation.

DAYS WITH COLD, CLOUDY EASTERLY WEATHER. DURHAM OBSERVATORY 1938-1962



PART 2

RATES OF SUNSHINE PRODUCTION IN AIR MASSES

INTRODUCTION

The second part of this thesis discusses the adjusted frequency distributions of daily sunshine duration (Fig. 11).

Chapter 7 observes that the variations of frequencies within individual adjusted frequency distributions are complex. The forms of the curves are very irregular and a casual inspection of Figure 11 does not detect any regular variations in these forms. Therefore, these variations are simplified in Chapter 7. The frequencies of each 10% group of sunshine durations are studied collectively on the bases of wind direction and time of year (Fig. 22).

This analysis describes a three-fold subdivision of sunshine durations expressed as percentages of the possible. The frequencies of days with 0 - 9% of the possible duration vary in a unique way according to wind direction and time of year. Therefore, these are termed 'low' sunshine amounts. Similarly, the frequencies of 'medium' (days with 10% - 59% of the possible duration) and 'high' (days with over 79% of the possible duration) amounts vary uniquely according to time of year and wind direction.

Chapter 8 proposes that these variations in the frequencies of low, medium and high sunshine amounts can be explained in terms of air mass properties. The chapter discusses the general significance of a classification of days according to wind direction and it suggests that this is essentially a classification according to air mass type; the properties of days with a particular wind direction being determined by the characteristics of the air mass which commonly invades the British Isles from that direction. Chapter 8 assumes that the frequencies of low, medium and high sunshine amounts observed on days with particular wind directions are indicative of the 'rates of sunshine production' within air masses. The frequencies of low, medium and high rates of sunshine production within air masses are described.

Unfortunately, the association between mean daily wind directions and air mass types is imprecise. The Conclusion (page 167) examines a number of problems which cause this imprecision. These problems include the contrasts between surface and geostrophic wind directions, the modifications of the properties of an air mass by the curvature of its trajectory or the arrival over the British Isles of different air masses from similar directions.

Consequently, this re-phrasing of the analysis of percentage sunshine durations fails to provide a basis for a general explanation of the relationships described by this thesis. The explanations contained in Chapter 9 deal with such isolated controls as the seasonal changes in the intensity of solar radiation, and orographic uplift and subsidence of the atmosphere.

CHAPTER 7

ADJUSTED FREQUENCY DISTRIBUTIONS

This chapter describes the contents of the adjusted frequency distributions of daily sunshine duration (Figure 11). It observes that when sunshine durations, expressed as percentages of the possible, are differentiated according to wind direction and time of year they distribute into three categories each of which varies uniquely according to these factors. "Low" amounts are overwhelmingly associated with winds of the eastern group in winter. "Medium" amounts have peak associations with winds of the western group in summer. "High" amounts have peak associations with winds of the western group in winter and with those of the eastern group in summer. However, there are many irregularities in curve form in Figure 11 and these observations are made only after considerable smoothing of these irregularities.

Two methods of eliminating these irregularities are attempted. The first deals with the frequency distributions individually. The linear regressions of percentage frequencies upon the duration axes are used to determine the "mean slopes" of the frequency distributions. This provides a graphical illustration of some general variations in Figure 11 but it is not an acceptable statistical measure because it excludes days with 0 - 9% of the possible sunshine duration.

The second method involves a collective study of the frequency distributions. This examines the variations, according to time of year and wind directions, of each 10% group and it demonstrates the significance of the three categories of sunshine duration which were mentioned previously.

A. MEAN SLOPES

Despite the irregularities in the individual curves in Figure 11 some general variations among their forms are noted by a brief glance at this diagram. These general variations are observed by comparing the graphs associated with the winds of the eastern and western groups respectively.

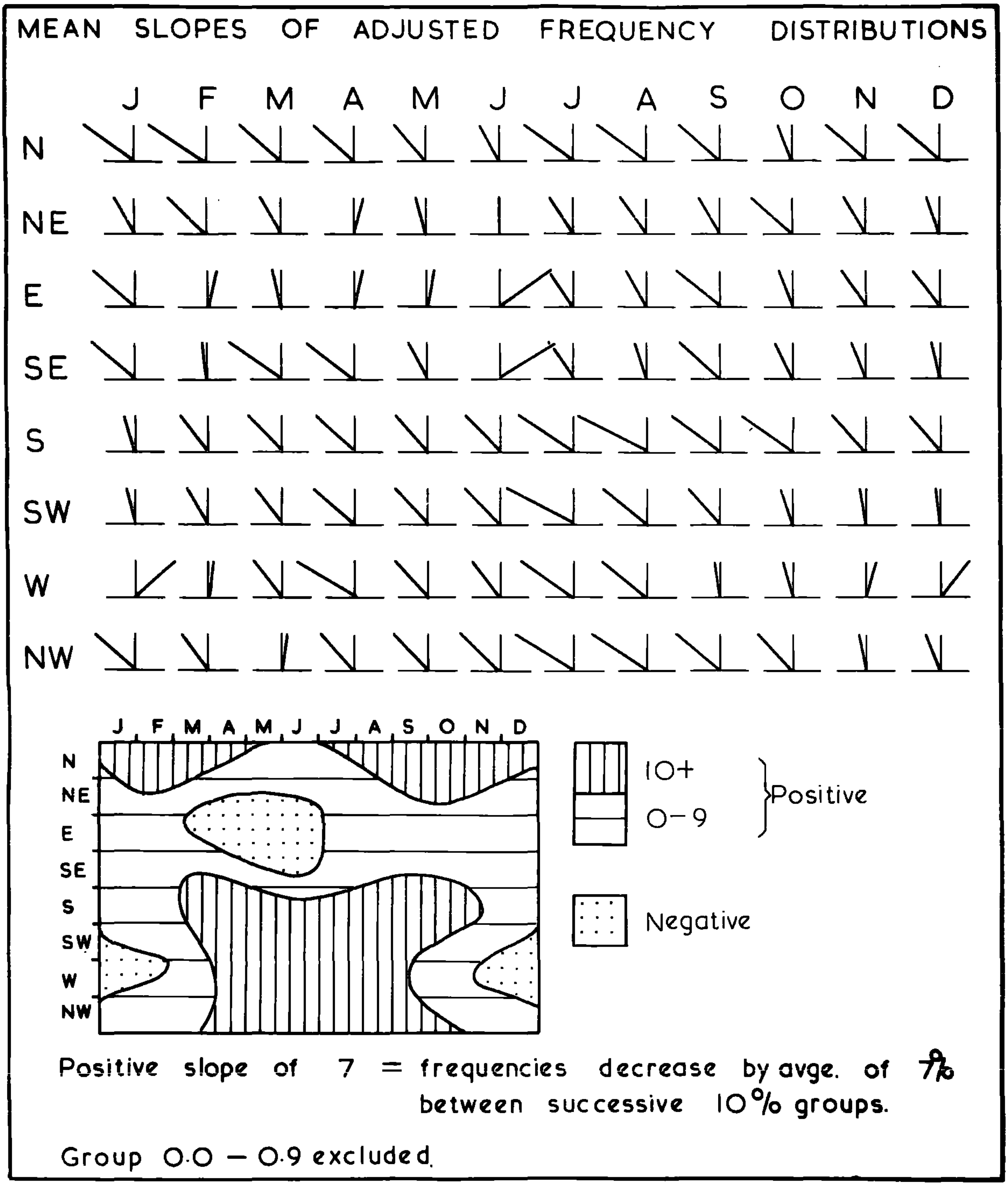
Broadly speaking, the graphs associated with the winds of the western group have relative deficiencies of the highest amounts of sunshine in summer. In winter these deficiencies are absent or they may be replaced by excesses. Excesses of the highest amounts of sunshine are observed with W winds in January and December.

The reverse applies to the data observed with winds of the eastern group. In these cases the highest amounts of sunshine are relatively common in summer and are absent in mid winter.

These variations are studied precisely by the calculation of the linear regressions of frequencies upon the duration axes. This is intended to give a measure of the mean slope of each frequency distribution. In most cases the frequencies of days with 0 - 9% of the possible are so great that the inclusion of these would distort the mean slope in an unacceptable manner and so these days have been excluded from the calculation. Consequently the statistics derived from these calculations are not true regressions and they will only be termed the "mean slopes" of the frequency distributions.

These mean slopes are shown in Figure 21 and their variations are given in Tables 34 and 35. "Positive" slopes are those which indicate a decrease in frequency with increasing sunshine duration and vice-versa. Mean slopes of +3 have a mean decrease in frequency of 3% (percentage of total observations per frequency distribution) with each 10% increase in sunshine duration.

A digest of these results is contained in the isopleth diagram in Figure 21. The general contrasts


MEAN SLOPES OF ADJUSTED FREQUENCY DISTRIBUTIONS

Positive slope of 7 = frequencies decrease by avge. of 7% between successive 10% groups.

Group 0.0 — 0.9 excluded.

FIGURE 21

between winds of the eastern and those of the western groups are confirmed by Figure 21 though this also indicates a number of individual exceptions.

The winds of the western group are associated with pronounced positive slopes in summer and with either shallow positive slopes or even negative slopes in winter (Table 34). This is due to the relative deficiencies of the highest amounts of sunshine in summer, and the relative excesses of these amounts in winter which were noted in Figure 11.

TABLE 34. WINDS OF WESTERN GROUP: MEAN SLOPES OF ADJUSTED FREQUENCY DISTRIBUTIONS, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	Jan.	Feb.	Mar.	Apr.	May	June
S	+3	+7	+9	+10	+8	+10
SW	+2	+5	+7	+12	+8	+10
W	-11	-1	+8	+15	+8	+7
NW	+11	+7	-1	+9	+10	+12

	July	Aug.	Sept.	Oct.	Nov.	Dec.
S	+15	+19	+14	+14	+9	+9
SW	+19	+11	+9	+3	+1	+1
W	+14	+12	+1	+3	-2	-9
NW	+16	+15	+12	+10	+1	+3

Excludes days with 0 - 9% of possible sunshine duration.

Slope of +3 = percentage frequency decreases by 3% per 10% increase in sunshine duration.

Days with S winds in August and SW winds in July experience mean decreases in frequency of almost 20% with each 10% increase in sunshine duration. W winds have by far the greatest seasonal change in mean slope though they have a lower positive component than S or SW winds throughout the year.

Changes with the winds of the eastern group are less regular than those observed in Table 34. Generally they are associated with maximum positive slopes in winter and either negative or shallow positive slopes in summer. However there are important exceptions to this rule (Table 35).

TABLE 35. WINDS OF EASTERN GROUP: MEAN SLOPES OF ADJUSTED FREQUENCY DISTRIBUTIONS, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	Jan.	Feb.	Mar.	Apr.	May	June
N	+14	+16	+12	+11	+9	+5
NE	+5	+10	+5	-2	+3	0
E	+11	-2	+2	-3	-1	-14
SE	+1	+1	+14	+13	+5	-15

	July	Aug.	Sept.	Oct.	Nov.	Dec.
N	+13	+14	+11	+4	+11	+11
NE	+6	+6	+6	+11	+6	+4
E	+9	+5	+12	+4	+7	+7
SE	+6	+3	+11	+4	+4	+2

Excludes days with 0 - 9% of possible

Slope of +3 = percentage frequency decreases by 3% per 10% increase in sunshine duration

For example on days with N winds the expected reduction of the positive component in the slope occurs from January to June but in July and August there are strong secondary peaks in this component. Similarly, days with NE winds suffer a pronounced unexpected reduction in the positive slope between November and January.

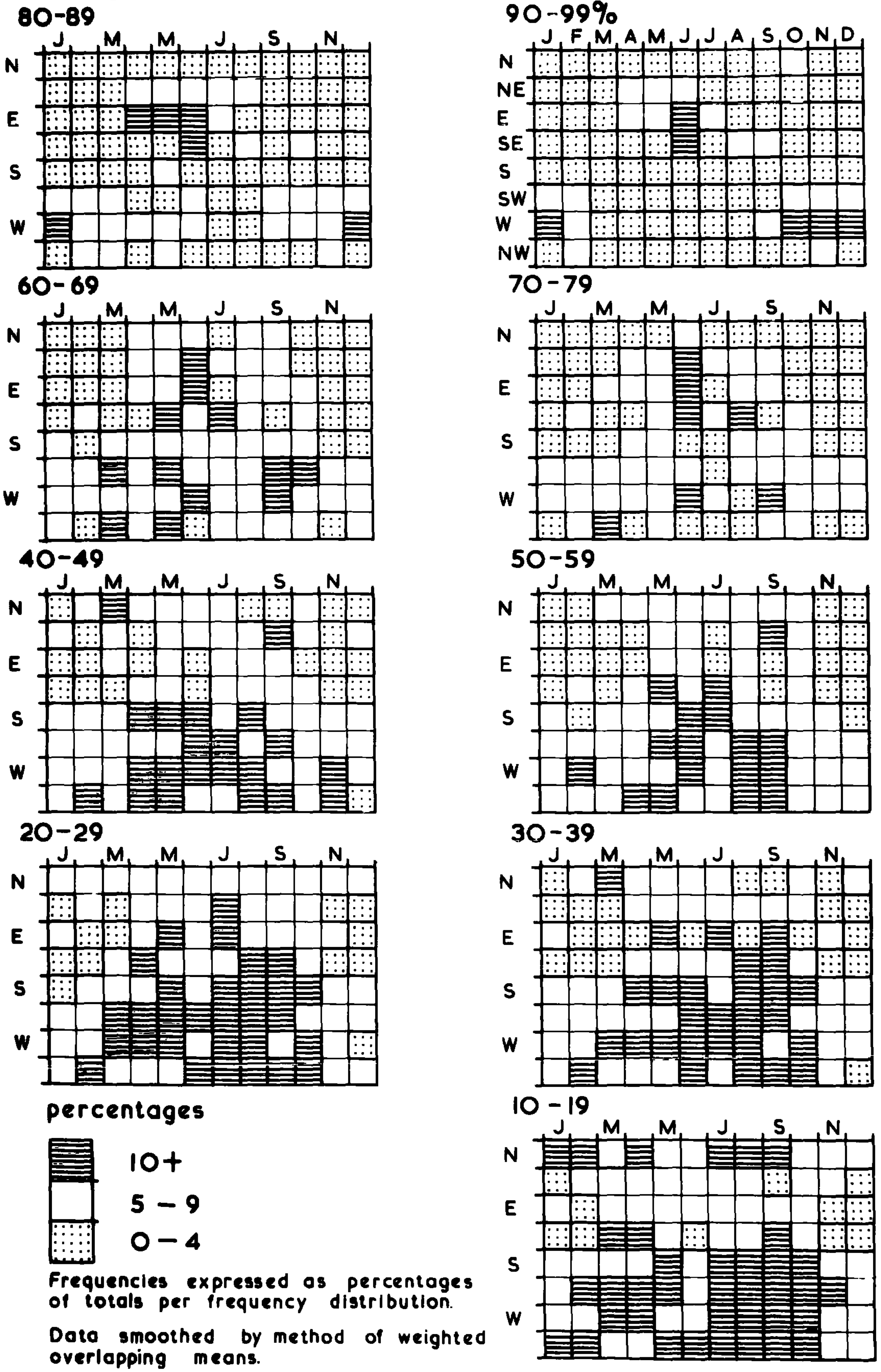
B. 10% GROUPS

This analysis examines the frequencies of each 10% group. It discusses the variations in frequency, according to wind direction and time of year, of days with 0 - 9%, 10 - 19% etc. of the possible sunshine duration. The results show that the variations observed on days with 0 - 9% of the possible are unlike those observed with any other sunshine amounts. The variations observed on days with each of the five groups between 10% and 59% of the possible are basically alike. Similarly, those observed on days with 80 - 89% and 90 - 99% of the possible are also alike. The patterns observed in these three cases are fundamentally different and they are the basis for distinguishing "low", "medium" and "high" amounts of sunshine.

Figure 22 contains nine diagrams showing the variations, according to wind direction and time of year, in

FIG 22

MONTHLY WIND RELATIONSHIPS OF EACH 10% GROUP OF THE ADJUSTED FREQUENCY DISTRIBUTIONS.



Frequencies expressed as percentages of totals per frequency distribution.

Data smoothed by method of weighted overlapping means.

the frequency of each 10% group. The tenth diagram, referring to days with 0 - 9% (low amounts) of the possible, is shown in Figure 23. The values contained in these diagrams are not the actual frequencies of each 10% group but a weighted overlapping mean (page 177). These are used since they reduce the major irregularities in the forms of the curves in Figure 11.

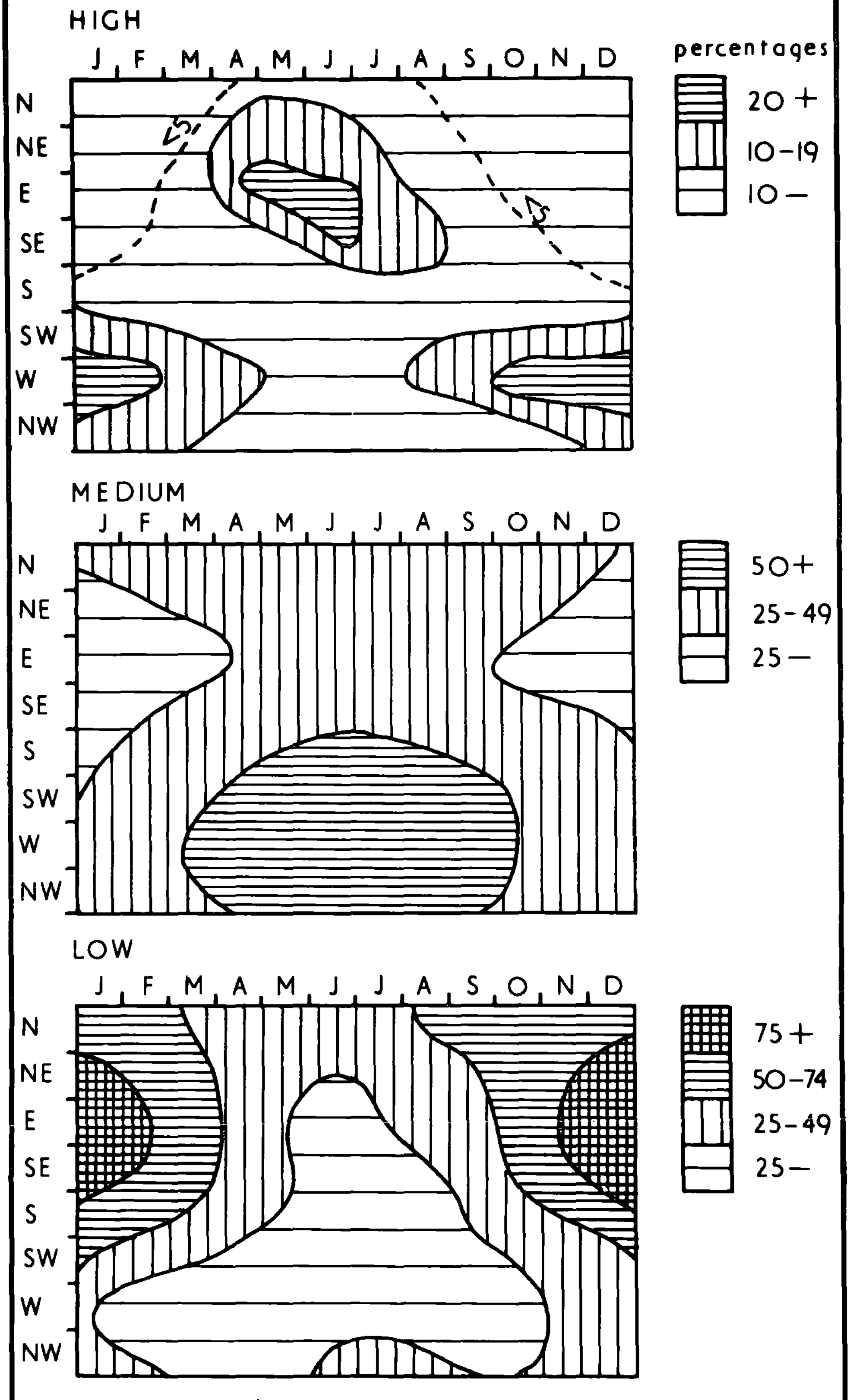
Figure 22 shows that the properties of the 10% groups vary considerably. The higher amounts of sunshine, especially groups 80 - 89% and 90 - 99% are, of course, rare but they are relatively common with winds of the eastern group in summer and those of the western group in winter. For example, days with 90 - 99% of the possible sunshine amount include over 10% of all days with W winds from October to January and over 10% of all days with E and SE winds in June.

The essential feature with lower amounts of sunshine is the shift of peak frequencies with winds of the western group from winter to summer. This shift is not complete in the cases of days with 60 - 69% and 70 - 79% of the possible but in the cases of all groups below this in Figure 22 it is fully established. However it is absent from days with 0 - 9% of the possible duration (Figure 23).

The high frequencies of days with 80 - 89% and 90 - 99% of the possible with winds of the eastern group in summer are paralleled by similar peaks among lower durations. There is no reduction in the magnitude of this peak in the cases of days with 60 - 69% and 70 - 79% of the possible but it is much reduced on days with smaller durations (Figure 22). An entire reversal in this property of winds of the eastern group is observed when durations fall to 0 - 9% of the possible (Figure 23). In this case there are strong winter maxima. Over 80% of days with winds of the eastern group in December and January have 0 - 9% of the possible sunshine duration.

This brief description has evaded an interesting feature of the diagrams in Figure 22 because it has emphasised their contrasts and ignored the similarities which are occasionally observed between adjacent diagrams. For example, days with 80 - 89% and those with 90 - 99% of the possible vary in the same way according to wind direction and time of year. Both are relatively common on days with winds of the western group in winter. Comparable uniformity is observed among the five diagrams referring to sunshine durations between 10% and 59% of the possible duration. In these cases the highest frequencies are observed on days with winds of the western group in summer.

MONTHLY WIND RELATIONSHIPS OF HIGH, MEDIUM & LOW AMOUNTS OF SUNSHINE



Frequencies expressed as percentages of totals per frequency distribution.

FIG 23

This emphasis upon the similarities between adjacent diagrams in Figure 22 suggests a basic three-fold subdivision of sunshine durations. 'High' sunshine amounts (over 80% of the possible) are most common on days with winds of the eastern group in summer and on days with winds of the western group in winter. 'Medium' amounts (10 - 59% of the possible) are most common on days with winds of the western group in summer. 'Low' amounts (0 - 9% of the possible) are most common on days with winds of the eastern group in winter (Figure 23). Days with 60 - 69% and 70 - 79% of the possible duration are considered to be transitional in this respect.

It must be stressed that precise limits have been allocated to each of these three groups simply as a convenience to aid their definition. These limits are arbitrary since they are derived from an arbitrary ten-fold subdivision of sunshine durations. Clearly high, medium and low sunshine amounts would have different limits if alternative group intervals or limits had been used within the adjusted frequency distributions of sunshine duration (Figure 11). The presence of a wide transition interval between high and medium amounts demonstrates this.

Particularly arbitrary is the upper limit of low sunshine amounts. The similarities between Figures 16 and 17 demonstrate that under most circumstances sunless days control the frequencies of days with 0 - 9% of the possible duration. In this respect, therefore, a duration of 0% of the possible would be a suitable upper limit for the lowest of these three groups of sunshine amounts.

C. HIGH, MEDIUM AND LOW SUNSHINE AMOUNTS

1. HIGH SUNSHINE AMOUNTS

High sunshine amounts occur on days with 80 - 89% and 90 - 99% of the possible sunshine duration (Table 90). The frequencies of these high amounts vary uniquely according to wind duration and time of year. These variations are summarised in Figure 23.

This diagram is basically similar to Figure 22 since it is constructed by simply adding the corresponding frequencies of the two groups. For example, the percentage frequencies of 80 - 89% and 90 - 99% of the possible sunshine duration on days with S winds in February are 1.3% and 1.5% respectively. Therefore the percentage frequency of high sunshine amounts on days with S winds in February is 2.8%. Since this addition produces a large range of frequencies it is justifiable to use isopleths in Figure 23.

High sunshine amounts are particularly common on days with winds of the eastern group in summer, and on days with winds of the western group in winter (Table 90). They occur on over 20% of all days with E winds in May, with E and SE winds in June, and with W winds in December and January. The peak frequency (30%) occurs on days with W winds in January.

Beyond these peak periods the frequencies of high amounts of sunshine are low. They are totally absent on days with many of the winds of the eastern group in winter. In July they occur on as few as 4% of all days with SW winds, 5% of all days with W winds and 2% of all days with NW winds.

2. MEDIUM AMOUNTS

These cover a wide range of sunshine durations (10 - 59% of possible) and so they are very common (Table 91). They are much more common with winds of the western than with those of the eastern groups though in both cases their peak frequencies occur in summer. This summer peak is especially pronounced with winds of the western group.

Medium sunshine amounts occur on over 60% of all days with W winds in April and August, with SW winds in July, with S winds in August and with NW winds in May. Their peak frequency is 68% of all days with S winds in August.

The lowest frequency of medium amounts of sunshine (7% of days) occurs with SE winds in December and January.

3. LOW AMOUNTS

The frequencies of low sunshine amounts (0 - 9% of possible) are extremely variable (Table 89). They occur on 90% of all days with SE winds in December, and on only 5% of days with W winds in June.

There are two basic components among the variations in the frequencies of low sunshine amounts. The seasonal component involves a winter maximum and a summer minimum. However, on days with NW and N winds there are mid summer secondary maxima in Table 89.

Superimposed upon this seasonal component are variations according to daily wind direction. Low sunshine amounts are commoner on days with winds of the eastern group than on days with winds of the western group.
The greatest contrasts between days with different wind directions are observed in winter.

CHAPTER 8

RATES OF SUNSHINE PRODUCTION IN AIR MASSES

In the previous chapter this analysis was formulated in terms which are satisfactory for descriptive purposes but which are unsatisfactory for explanatory purposes. The analysis has distinguished between days on the basis of wind direction. Quite expectedly there are wide variations in the sunshine properties of days distinguished in this way. Chapter 7 has described these variations.

The weakness of this procedure is its failure to describe the significance, in terms of weather conditions, of days distinguished according to wind direction. Until this problem is examined it is impossible to explain the sunshine variations which have been described and the analysis remains a purely empirical comparison of observations.

Chapter 8 attempts to rectify this deficiency by expressing the analysis in terms of air mass type rather than wind direction. This will allow a description of the variations of sunshine amounts according to air mass type and it may provide a basis for explaining the relationships observed in Chapter 7. Initially there is a general discussion of the association between air mass types and wind directions.

A. ASSOCIATION BETWEEN AIR MASS TYPE AND WIND DIRECTION

The British Isles are invaded by very unlike air masses. Each type of air mass tends to follow a characteristic route and approach the British Isles from a particular direction. Since the British Isles are roughly located at a focal point between air mass source regions these arrival directions generally vary between different types of air.

This discussion proposes that an analysis of the mean properties of days with a particular wind direction is, indirectly, an analysis of the mean properties of the air mass which commonly invades the British Isles from that direction. It proposes, for example, that the mean properties of days with NW winds correspond approximately to the mean properties of days with polar maritime air.

This association between a wind direction and an air mass type is extended to cover the whole range of wind directions used in this analysis.

Six types of air are distinguished. These are derived from Belasco's[1] classification of the surface air masses of the British Isles to enable a comparison between the results of this analysis and the mean air mass properties described by Belasco.

Unfortunately, the daily variations in air mass movement are complex and these variations seriously modify air mass properties. Belasco therefore recognised subtypes of each air mass. Usually he distinguished between subtypes possessing cyclonic, anticyclonic and straight trajectories, but he ignored the variations in radius of curvature.

It is proposed that this association between a wind direction and an air mass is valid since the analysis deals

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1. BELASCO, J.E., Characteristics of the air masses over the British Isles. Geophysical Mem., 87, 1952

with groups of days drawn from large monthly samples[1]. This use of large samples of days with particular wind directions may provide a simple method of estimating the mean properties of each air mass.

The remainder of this chapter describes the air mass types which are associated with each wind direction and utili~~s~~zes the results contained in Chapter 7 to describe the frequencies of high, medium and low sunshine amounts in each air mass.

B. AIR MASSES

1. POLAR MARITIME (ARCTIC): Pm(A)

This air mass includes two of Belasco's polar air

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[1] The Conclusion (page 173) raises three objections to this proposal. Firstly, it notes that the effects of trajectory curvature upon the properties of an air mass are too pronounced to permit a discussion of the results of this analysis in terms of the "mean properties" of air masses. Secondly, it observes that, in some cases, unlike air masses approach the British Isles from similar directions. Finally, it stresses that air mass movement is described by the geostrophic wind direction which usually differs from the surface wind direction.

masses (P_1 and P_2). These are classed together as Pm(A) air because they both originate to the north and east of Iceland and approach Britain from the north. They mainly arrive as north winds though they have a substantial north east component. Therefore Pm(A) air will be associated basically with N winds. Nevertheless it will be assumed that some of the characteristics of days with NE winds may also be due to the properties of Pm(A)air.

Pm(A) air is uncommon and it is usually experienced on an average of about 6% of days (Belasco[1]). This frequency is slightly greater in late winter (about 7%) than in summer (about 5%) but it has an abrupt maximum in May (14%),

2. POLAR MARITIME (DIRECT): Pm(D)

Belasco's types P_3 and P_4 are included in Pm(D) air masses. This air originates to the north west and north of Iceland and it approaches Britain by a fairly direct path from this source. Therefore Pm(D) air is associated with NW winds.

The monthly mean frequencies of Pm(D) air are of the order of 10% of all days. There is a pronounced

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[1] BELASCO, J.E., op.cit., 1952.

summer maximum (June 13%, July 15% and August 13%) and a secondary maximum in January (13%).

3. POLAR MARITIME (INDIRECT): Pm(I)

This includes Belasco's types P_5 and P_6. It also originates to the north west and west of Iceland but it follows an indirect southerly route. It arrives at the British Isles basically from the west but it has a strong south west component. Therefore Pm(I) air is basically associated with W winds and it is partly associated with SW winds.

This is the most common air mass since it occurs on about 15% of all days. Again there is a summer maximum (June 19%, July 18% and August 18%).

4. TROPICAL MARITIME: Tm[1]

This includes Belasco's types T_1 and T_2 which originate to the south west of the Azores and approach the British Isles fairly directly. It arrives mainly from the south west though it has a strong west component. Therefore Tm air is mainly associated with SW winds and is partly associated with W winds and S winds.

Tm air occurs on about 8% of all days. It is most frequent in winter (November 10%, December 8%,

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[1] The Conclusion discusses a variety of objections to the general procedure of relating wind directions and air masses. An important objection is that in some cases unlike air masses invade the British Isles from similar directions. This problem is acute in the case of SW winds because these are associated with Tm and Pm (Returning) air masses. The implications of this problem are discussed in the Conclusion (page 178).

January 9% and February 10%). There is a pronounced spring minimum (April 4% and May 4%) in the frequency of Tm air.

5. TROPICAL CONTINENTAL: Tc

This includes Belasco's types T_3 and T_4 which originate in south Europe in summer and in north west Africa. This air approaches the British Isles basically from the south though it has a strong south east component. Therefore while it is mainly associated with S winds it is partly associated with SE winds.

Monthly frequencies of Tc air are low. It has a maximum average frequency of 9% of days in October and a minimum of 2% of days in December.

6. POLAR CONTINENTAL: Pc

Belasco distinguishes between two main groups of polar continental air masses. The first, including types A_1 and A_2, originates in Eurasia to the north of 50°N. This is absent from April to November and its source region is the cold anticyclone over Eurasia. The second group, type C, originates in Eurasia to the south of 50°N and it occurs throughout the year.

Pc air is associated with E, SE and NE winds. In winter it includes types A_1, A_2 and C, and its percentage frequencies are 18% of days in January, 12% of days in March, 10% of days in December and April, and 8% of days in November. Pc air in mid summer (type C) is rare (July 2 %) though it has a pronounced secondary peak (13%) in May.

The associations between high, medium and low amounts of sunshine and the six air masses are described in the present chapter and are explained in Chapter 9.

It is assumed that air masses control sunshine duration indirectly through their cloud forming processes and that sunshine durations, when expressed as percentages of the possible, are indirect measures of the efficiency of these processes. Bilham and Lewis[1] arrived at basically the same conclusion when they considered that expressions of sunshine duration in percentages of the possible are measures of "the average frequency with which a certain state of the sky occurs during the period of daylight."

However, the sunshine record reflects cloud

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1. BILHAM, E.G., AND LEWIS, L.F., The frequency of days with specified duration of sunshine. Prof.Notes, No 69, 1935.

conditions with only a moderate efficiency. It ignores night conditions and this is especially unfortunate in winter. Furthermore it does not operate with uniform efficiency with all types of cloud. Durations are overestimated when the cloud is intermittent because of the blurring of the trace upon the recording card. Additionally the extent of clear sky is underestimated with towering clouds since their vertical extent intercepts some sunshine.

Despite these considerations the sunshine record provides a best-estimate of the efficiency of cloud forming processes throughout the day. When these processes are efficient much cloud is produced and the "rate of sunshine production" is low. In the following discussion high, medium and low rates of sunshine production by air masses will be described. These are defined using the criteria derived in Chapter 7.

B. RATES OF SUNSHINE PRODUCTION

1. HIGH RATES (OVER 80% OF POSSIBLE)

Table 90 and Figure 23 show that high rates of sunshine production are relatively common in maritime air masses in winter and in continental air masses in summer. at Durham.

This is indicated by their occurrence on over 10% of days with SW, W and NW winds in most months from October to March, and by their occurrence on over 10% of days with NE, E and SE winds in most summer months. In both of these groups of circumstances the highest frequencies are about 25% of all days.

By contrast the high rates of sunshine production are very rare, or absent with continental air masses in winter, and they are relatively uncommon with the maritime air masses in summer. From September to March it is very unusual for the frequencies of these rates to exceed 5% of days with winds of the eastern group. Similarly in July these frequencies do not exceed 5% in association with any of the winds of the western group.

The contents of Table 90 indicate that there are marked contrasts between the individual air masses in the maritime and continental groups in this respect.

a. Maritime Air Masses

Pm(A) air is unique because in winter it is not associated with high rates of sunshine production at Durham. However in summer the frequencies of these rates on days with N winds accord with their usual frequencies with maritime air masses.

Pm(I) air is much more closely associated with high rates of sunshine production in winter than is either Pm(D) or Tm air. Two features of the data in Table 90 suggest this.

Firstly the peak frequency with W winds (30% in January) is considerably greater than that with NW winds (17% in February) or that with SW winds (14% in November and December). These winds are predominantly associated with Pm(I), Pm(D) and Tm[1] air masses respectively.

Secondly the winter period of peak frequency is longest and most continuous with W winds. These are associated with high rates on over 17% of days in all months from September to February whereas on days with NW winds these frequencies only exceed 10% in November, February and March.

Also in summer high rates of sunshine production are most common with Pm(I) air and are least common with Pm(D) air.

b. Continental Air Masses

The continental air masses may be contrasted according to the period of peak frequency of high rates of sunshine duration. This peak is earliest (April) with continental air masses arriving from the NE and it is latest

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[1] See Note 1 on page 117.

(June) with those arriving from the SE. This contrast is emphasised by the exten~~t~~sion of the high frequencies (over 10%) into September with SE winds whereas in the cases of NE and E winds it terminates in July.

2. MEDIUM RATES (10% TO 59% OF POSSIBLE)

The basic variations in the frequency of medium rates of sunshine production are two-fold since these are commoner with the maritime air masses and are commoner in summer. Consequently, the highest frequencies of medium rates occur with the maritime air masses in summer and the lowest frequencies occur with the continental air masses in winter. This is shown by their occurrence on over 50% of days with winds of the western group in most months from April to September and on less than 25% of days with NE, E and SE winds from November to January.

a. Maritime Air Masses

Throughout the year medium rates are relatively uncommon in Pm(A) air, which, in this respect, behaves like a continental air mass.

There are only very minor differences between the three remaining maritime air masses. The two polar air masses have peak associations with medium rates in spring whereas this peak is delayed until mid-summer with Tm air.

The peak frequency with NW winds (64%) occurs in May, that with W winds (64%) occurs in April, while that with SW winds (60%) is in July.

A second minor contrast between these air masses involves the duration of the summer period of high association with medium rates because this is greatest with Pm(D) air and it is least with Tm air. For example the mean frequencies of medium rates on days with NW winds exceed 50% from February to October, whereas with SW winds these frequencies are exceeded only from April to September.

. Continental Air Masses

A minor difference among continental air masses distinguishes those arriving as SE winds from the remainder. The period of closest association with medium rates ommences earliest with those continental air masses rriving from the SE. In April medium rates are roughly wice as common on days with SE winds as on those with E r NE winds.

. LOW RATES (LESS THAN 10% OF POSSIBLE)

The basic two-fold variations in the frequency f low rates of sunshine production are a reverse of those bserved with the medium rates. In this case the highest frequencies occur with the continental air masses and in winter. Hence low rates are commonest with the continental air masses in winter and they are rarest with the maritime air masses in summer. The frequencies associated with winds of the eastern group exceed 75% of days in November, December and January, and those associated with S, SW and W winds are usually below 20% of days from May to September.

a. Continental Air Masses

A minor contrast between the individual continental air masses occurs in winter. The early winter rise in the frequency of low rates is later with those air masses arriving from the SE than with those arriving from the E and NE. Hence in October 42% of days with SE winds experience low rates whereas the comparable frequencies with NE and E winds are 62% and 61% respectively.

b. Maritime Air Masses

The properties of Pm(A) air again deviate from those of the remaining maritime air masses. The peculiarities of this air mass in summer are especially interesting because at this time it is associated more closely with low rates than is any other air mass. In August the frequency of these rates on days with N winds exceeds 50% whereas their next highest frequency (with NW winds) is only 33%. Furthermore in mid-winter Pm(A) air resembles continental air in this respect because in December 73% of days with N winds have low sunshine amounts.

Chapter 9

DISCUSSION

This analysis has described a three-fold contrast among rates of sunshine production. Low and medium rates are common under most circumstances but the peak frequencies of the former are observed on days with winds of the eastern group in winter while peak frequencies of the latter are observed on days with winds of the western group in summer. High rates are rarely observed but they most commonly occur on days with winds of the eastern group in late spring and early summer, and on days with winds of the western group in winter.

This three-fold subdivision is justified by a general comparison of the 96 frequency distributions obtained when daily sunshine durations are expressed as percentages of the possible and classified according to month and daily wind direction (Fig. 22). The limits of the three rates of sunshine production are arbitrary since they are controlled by the initial subdivision of sunshine durations into 10 groups, each corresponding to a range of 10% of the possible duration (page 67). Thus, low rates of sunshine production are given an upper limit of 9% of the possible but the majority of these days are sunless (compare Figures 16 and 17). Medium rates are defined by upper and lower limits of 10% and 59% of the possible duration. Figure 22 implies that all sunshine durations within these limits vary similarly according to wind direction and time of year. High rates are observed on days with 80% or more of the possible duration.

This chapter will discuss the observed variations in the frequenc~~y~~ies of low, medium and high rates of sunshine production. The discussion is based on the assumption that sunshine durations are determined by cloud conditions throughout the period of daylight. Consequently, the discussion assumes that daily rates of sunshine production are determined by the processes which control cloud formation. An important implication of this assumption is that sunshine records provide an indirect measure of total daily cloud conditions which are otherwise ignored at a normal climatological station. Rates of sunshine production inversely express the density of cloudcover during the hours of daylight.

Unfortunately, a number of problems are involved in this basic assumption.

Firstly, it must be stressed that observed sunshine durations are not rigidly controlled by cloud conditions. This arises partly from the inability of the Campbell-Stokes sunshine recorder to detect short wave radiation of intensity below 0.2 cals.cm^2 min. Weak sunshine does not burn the recording card. Therefore, thin stratiform cloud veils are more likely to be detected by the recorder in winter, when solar radiation passes at a low angle through the cloud, than in summer.

Additionally, the effects of cloud type must be stressed. A gap of given size in stratiform cloud is likely to permit bright sunshine to reach the surface for longer periods than a similar gap in cumuliform cloud. The summits of cumulus clouds intercept a significant proportion of the incoming sunshine. A further instrumental problem concerns the overestimation of sunshine duration by the Campbell-Stokes recorder during periods of short bursts of intermittent sunshine.

Many factors control the formation and dissipation of cloud. Adiabatic, radiative and advective cooling, the dominant cloud forming processes, are affected by the intensity of solar radiation, surface temperature, environmental lapse rate, wind speed, surface friction, vapour pressure etc. A thorough discussion of rates of sunshine production must consider the effects of each of these factors.

However, this analysis has emphasised two components of the variations in the frequencies of these rates, namely, the seasonal component and that determined by daily wind direction. These components are each affected by many factors but they are dominated by a small number of factors.

The seasonal component is primarily a function of seasonal changes in the intensity of solar radiation. It is also affected by seasonal changes in the circulation pattern, such as frequent anticyclogenesis over Scandinavia in spring, and by changes in the vapour pressure of the air.

The relief of north England is complex and the variations of the frequencies of rates of sunshine production among days with different wind directions are partially functions of orographic uplift and subsidence. However, these variations are considerably affected by the association of individual directions with the arrival of unlike air masses over north east England.

This discussion examines separately each of these components of the variations described by this thesis.

A. SEASONAL VARIATIONS

There are pronounced seasonal variations in the frequencies of rates of sunshine production.

Low rates are relatively common in winter and their frequencies tend to be distributed upon a smooth curve between a December maximum and a June minimum. The amplitude of this curve is greatest on days with NE, E and SE winds and it is least on days with SW and W winds. This seasonal change implies a relatively frequent clearing of cloud covers in summer and this is reflected in high frequencies of medium rates of sunshine production at this time.

However, on days with winds of the eastern group in spring and early summer, and on days with winds of the western group in winter, this clearing is often intense and high rates of sunshine production are common. Consequently, the seasonal variations in the frequency of medium rates are less regular than those of low rates. In June there are slight secondary minima in the frequency of medium rates on days with NE, E and SE winds. Usually medium rates are most common in July or August.

These seasonal variations are primarily functions of monthly mean daily receipts of solar radiation. The important process in this respect is the dissipation of stratiform cloud following the absorption of solar radiation by the cloud and at the earth's surface. The resultant surface warming encourages daytime turbulent mixing of the air and reduces its relative humidity.

However, the efficiency of this process depends partly upon the stability of the air and this is demonstrated by two relationships described in this analysis.

Firstly, the analysis detected summer secondary maxima in the frequencies of low rates of sunshine production on days with NW and N winds. These rates are observed on about 35% of days with N winds in June, July and August, while on similar days in spring they are observed on less than 20% of days. In August low rates are observed on 52% of days with NW winds. These mid summer peaks may be partly attributed to the formation of cumulus cloud in Pm (Arctic) and Pm air masses which commonly arrive as N and NW winds in the rear of depressions. The high daytime land surface temperatures of summer favour cloud formation in these unstable air masses.

Secondly, this analysis observed that high rates of sunshine production are relatively common on days with winds of the eastern group in spring and early summer. This reflects the efficiency of cloud dissipating processes within stable air masses during periods of intense solar radiation. Pc air masses invading the British Isles in spring and early summer are often stable in contrast to the more unstable varieties of mid summer.

Over the eastern North Atlantic Ocean and Europe a low index circulation often persists in May. This is marked by peak frequencies of blocking action under these circumstances (Rex[1], Sumner[2]).

A feature of the spring and early summer circulation of specific interest to this discussion, is the relatively high frequency of anticyclogenesis over Scandinavia. Britain is often within the circulation of these anticyclones and to the north of the front which frequently forms between their easterly airstreams and the maritime air masses which invade Europe. Occasionally, the Scandinavian anticyclone expands south westwards to envelop the British Isles (Miles[3]). Belasco[4] observed that in May the most common anticyclone affecting the British Isles is that centred to the north east and east (as opposed to anticyclones centred in the remaining quadrants) and the most common air over the British Isles during May anticyclonic spells is continental.

Consequently, spring and early summer Pc air masses are generally stable and their surface stability is emphasised by advective cooling over the North Sea (page 11). This high

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. REX, D.F., Blocking action in the middle troposphere and its effects upon regional climate. Tellus, 2, 275, 1950

2. SUMNER, E.J., Blocking anticyclones in the Atlantic-European sector of the northern hemisphere. Met.Mag., 88, 300, 1959

3. MILES, M.K., Whitsun holiday, 1955; eleventh-hour recovery of a "blocking anticyclone". Weather, 10, 237, 1955.

4. BELASCO, J.E., The incidence of anticyclonic days and spells over the British Isles, Weather, 3, 233, 1948

stability may, in association with the relatively high daytime land surface temperatures of spring and early summer, be responsible for the relatively common occurrence of high rates of sunshine production on days with winds of the eastern group.

However, haar cloud is occasionally formed within these air masses. Findlater[1] occasionally detected steep surface environmental lapse rates within these Pc air masses and attributed these to the presence of cells of particularly cold air at the inversion. These cells are not formed in situ but appear to develop from polar air which is incorporated into the anticyclone. The rapid uplift of moisture beneath these cells favours the formation of stratocumulus cloud at the inversion.

Variations in the vapour pressure of the air may be responsible for some seasonal changes in the frequencies of rates of sunshine production. The pronounced winter maximum in the frequency of high rates on days with winds of the western group may be largely attributable to the relatively low vapour pressures within maritime air masses in winter, This vapour pressure minimum, and the general absence of thermal convection within unstable air masses over the cold land surfaces, encourages clearing of cloud to the lee of the

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[1] FINDLATER, J., Thermal structure in the lower layers of anticyclones. Quart.J.R.met.Soc., 87, 513,1961

Pennines on days with winds of the western group in winter.

Another cause of seasonal variations in the frequencies of rates of sunshine production is the inability of the Campbell-Stokes sunshine recorder to detect weak sunlight. Throughout the year there is a possibility of thin cloud veils transmitting sufficient solar radiation to burn a trace on the recording card of this instrument. This is least likely to happen in winter when the radiation impinges on the cloud veil at a low angle.

B. VARIATIONS ACCORDING TO WIND DIRECTION

A second major component of the variations in the frequencies of rates of sunshine production is that determined by daily wind direction. Low rates are most common on days with NE, E and SE winds and they are least common on days with SW and W winds. These relationships apply to all months except June and they are most pronounced from October to March. Medium rates are compensatingly common on days with SW, W and NW winds and they are less common on days with NE, E and SE winds. The greatest frequencies of high rates are observed on days with E winds in April, May and June, and on days with winds of the western group in winter.

These variations are partially attributable to orographic uplift and subsidence. Westerly air streams over north England decend 2,000 feet during a 40 miles journey from the main Pennine watershed to Durham city. Lee-clearing of cloud during this decent discourages the occurrence of low rates of sunshine production on days with SW, W and NW winds. Easterly air streams rise 400 feet over the east Durham plateau. This uplift encourages the occurrence of low rates of sunshine production on days with N, NE, E and SE winds.

However, the variations in the frequencies of rates of sunshine production among days of different wind direction are also functions of air mass properties because the British Isles are invaded by unlike air masses from different directions. The conclusion of this thesis discusses the relationships between wind direction and air mass types, noting that the inter-relations and variations of air mass trajectories are too complex to permit a discussion of the properties of days with a particular wind direction in terms of the characteristics of one air mass. Therefore, there is no basis for a general discussion of this important cause of the variations in the frequencies of rates of sunshine production. Attention is drawn to the following air mass relationships which may be inferred from this analysis.

In winter high rates of sunshine production are commoner on days with W winds than on days with NW winds. This contrast may arise from tendencies for Pm air masses in the rear of depressions to arrive from the north west while Pm air circulating within ridges between depressions commonly arrives from the west.

Low rates of sunshine production are relatively common, and high rates are relatively uncommon,on days with N and NW winds in summer.This may be attributed to cumulus cloud formation over warm land surfaces in unstable Pm (Arctic) and Pm air masses circulating behind depressions to the east or north east of the British Isles.

In spring high rates are commoner on days with E winds than on days with NE winds. This contrast may arise from the tendency for Pm (Arctic) air masses to invade the country from a north east direction.

PART 3

RELATIONSHIPS BETWEEN DAILY SUNSHINE DURATION AND DAILY MAXIMUM TEMPERATURE

INTRODUCTION

This analysis relates daily observations of maximum temperature to those of sunshine duration. The relationships are differentiated according to time of year and wind direction. The results suggest that the basic factor controlling these relationships is the ratio between the daily receipt of shortwave radiation and the daily loss of long wave radiation. The evaporation of surface water modifies these relationships.

In Chapter 10 the coefficients of correlation between sunshine duration and maximum temperature are described in two parts.

Initially mid summer and mid winter conditions are compared. In January the two elements are either uncorrelated or they are negatively correlated. However in July they are positively correlated. The July positive correlation is much more pronounced on days with winds of the eastern group and with NW winds than on days with SW winds.

The second part of Chapter 10 contains monthly analyses of the correlation coefficients observed on days with NE and SW winds respectively. The results suggest a basic two-fold subdivision of the year. Positive correlations prevail during the summer period from March to September. During the winter period from October to February the two elements are either uncorrelated or they are negatively correlated. The transitions between these periods are abrupt.

Chapter 11 discusses these observations in two parts. It commences with a general discussion of the main processes affecting daily maximum temperatures. Daily surface warming is attributed basically to the absorption of short wave radiation and this process encourages a positive correlation between sunshine duration and maximum temperature. Daily surface cooling is partly a function of the transmission of long wave radiation and this process encourages a negative correlation between the two elements.

Finally Chapter 11 utilises the results of this analysis to discuss the relative importance of these two processes.

CHAPTER 10

RELATIONSHIPS BETWEEN DAILY SUNSHINE DURATION AND DAILY MAXIMUM TEMPERATURE

This description of the relationships between daily sunshine duration and daily maximum temperature is in two parts. It commences with a comparison of the conditions obtaining in July and January. This indicates that there are wide seasonal extremes in these relationships. Mid summer is characterised by positive correlations which are especially pronounced on days with winds of the eastern group and with NW winds. In mid winter the two elements are usually uncorrelated but on days with SW and W winds they are negatively correlated.

The second part of the analysis contains monthly accounts of the correlations observed on days with SW and NE winds respectively. SW and NE winds are included in this monthly analysis since they are associated with extreme tropical and polar influences respectively. This analysis is designed to detect the limits of the periods during which positive and negative correlations prevail. The 'winter' period, based upon monthly mean conditions, includes October, November, December, January and February. During this period there are no positive correlat~~t~~ion coefficients between the two elements. The 'summer' period, from March to

September, is characterised by positive correlations. The transitions between these subdivisions of the year are remarkably sharp in comparison with the relative uniformity which prevails within each period.

A. SEASONAL EXTREMES

These are described in separate accounts of the conditions observed in July and January. Within each month days are distinguished according to wind direction. Scatter diagrams, showing the relationships between these elements, are drawn for each wind direction in July and January. These diagrams are described numerically.

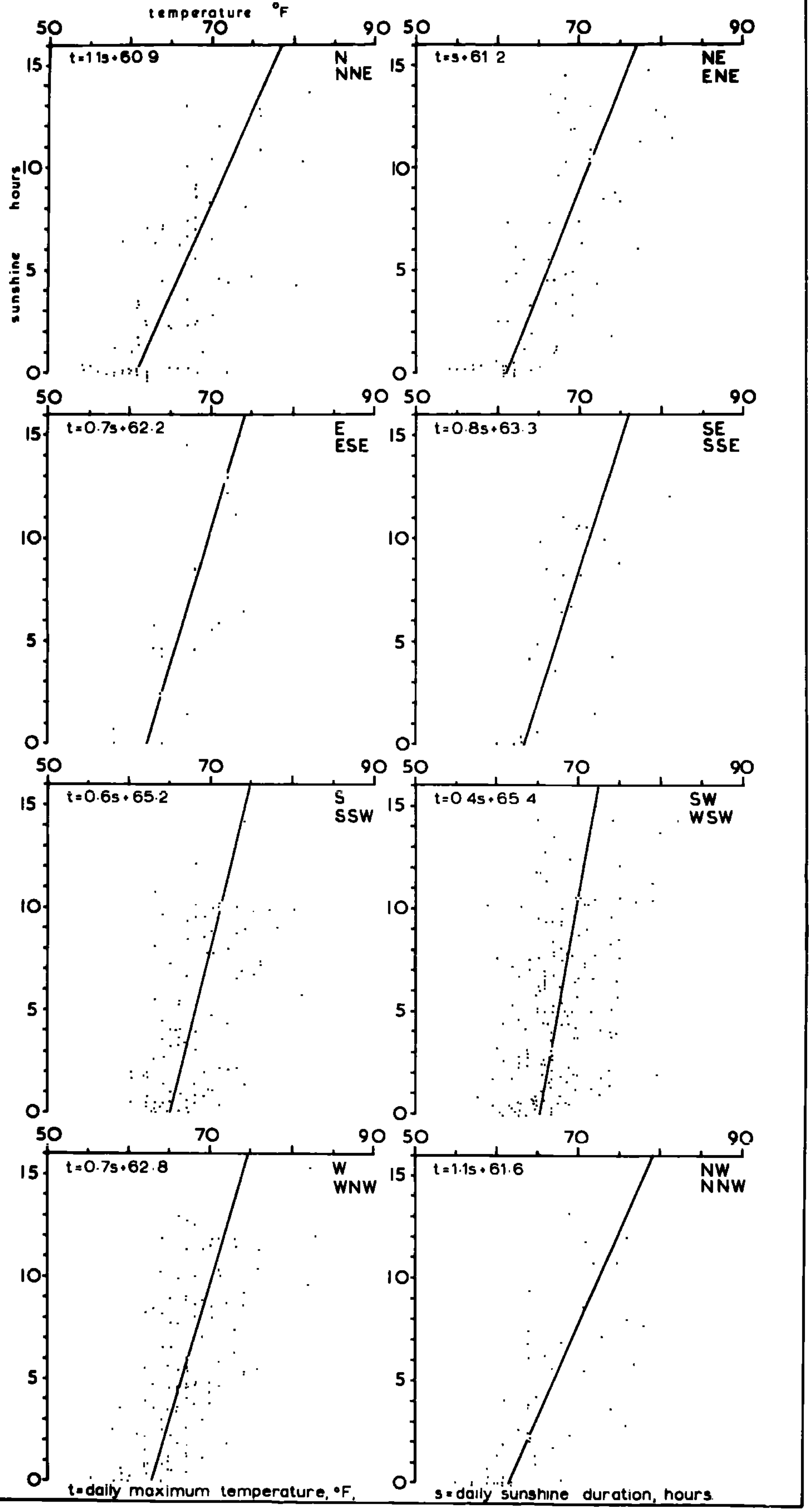
1. JULY

Figure 25 contains scatter diagrams each of which refers to days with a particular wind direction in July. The x-axes in these diagrams accommodate maximum temperatures and the y-axes accommodate sunshine durations.

The scatter diagrams indicate that under all circumstances there are positive relationships between these elements since high sunshine durations are often accompanied by high maximum temperatures. However these are not close relationships since in each diagram there are wide varia-

FIG 25

JULY RELATION BETWEEN DAILY OBSERVATIONS OF MAXIMUM TEMPERATURE AND SUNSHINE DURATION (PER WIND DIRECTION)



tions from this rule. A numerical analysis of each diagram is required to confirm the positive relationships and to demonstrate any differences which may exist among days with individual wind directions. The results of these analyses are shown in Table 38.

TABLE 38. JULY: RELATIONSHIPS BETWEEN SUNSHINE DURATION AND MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, 1937 TO 1961.

	N	NE	E	SE	S	SW	W	NW
a.	+0.66	+0.74	+0.59	+0.76	+0.51	+0.26	+0.60	+0.71
b.	76	64	17	24	87	159	109	50
c.	1.1	1.0	0.7	0.8	0.7	0.4	0.8	1.1

a = coefficient of correlation

b = number of days

c = regression of maximum temperature on sunshine duration. Value indicates the change in maximum temperature (^{o}F) per one hour increase in sunshine duration (Regression equation, Table 92).

These data confirm the observation that sunshine duration and maximum temperature are positively related on days with each wind direction in July. Significant positive correlations are observed in all cases. However Table 38 also indicates large variations in the magnitude of this coefficient and of the regression of maximum temperature upon sunshine duration.

The extreme range of correlation coefficients in Table 38 is large since the highest value (with SE winds) is +0.75 while the lowest value (with SW winds) is only +0.26. There are irregular fluctuations in the correlation coefficients between these extremes. For example, a pronounced trough is associated with E winds. Nevertheless there is a general contrast between days experiencing tropical influences and the remaining days since the lowest coefficients are associated with the former.

Similar variations are observed in the regression of maximum temperature upon sunshine duration. These regressions are shown upon each scatter graph in Figure 25 and in Table 38 they are expressed as increases in maximum temperature (^{o}F) produced by one hour increases in sunshine duration. The highest regression (1.1^{o}F with N and NW winds) is over twice as steep as the lowest (0.4^{o}F with SW winds). The steepest regressions are observed with NW, N and NE winds arriving from polar regions and the shallowest are observed with SW and, to a lesser extent, S winds arriving from tropical regions.

2. JANUARY

The relationships between sunshine duration and maximum temperature on days with each wind direction in January are shown in Figure 26. Basically this diagram indicates a lack of association between the two elements. This applies equally to days which are rare, such as those with

JANUARY. RELATION BETWEEN DAILY OBSERVATIONS OF MAXIMUM TEMPERATURE & SUNSHINE DURATION (PER WIND DIRECTION).

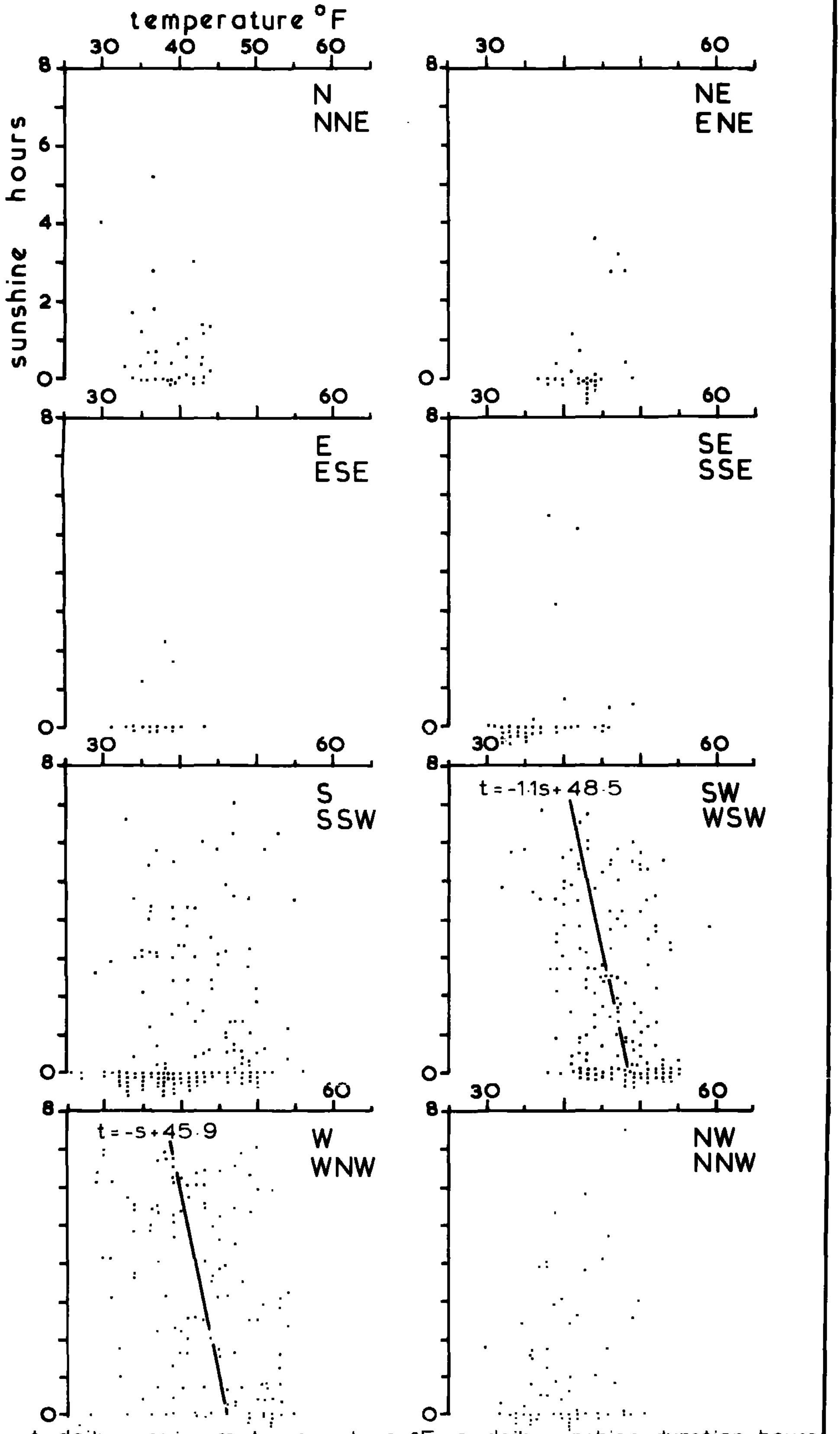


FIG 26

t=daily maximum temperature, °F; s=daily sunshine duration, hours.

E winds, and to days which are common, such as those with S winds.

However numerical analyses of these data suggest that negative relationships exist on days with SW and W winds (Table 39).

TABLE 39. JANUARY: RELATIONSHIPS BETWEEN SUNSHINE DURATION AND MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, 1938 TO 1962

	SW	W
a.	-0.50	-0.38
b.	162	126
c.	1.0	1.0

a = coefficient of correlation

b = number of days

c = regression of maximum temperature upon sunshine duration (regression equation, Table 93)

Negative correlation coefficients are observed on days with SW and W winds in January. The latter is very small but Student's "t" testing demonstrates that it is significant. In each of these cases the regressions of maximum temperature upon sunshine duration are surprisingly steep since they are comparable with the steepest regressions observed in July.

Figure 26 indicates that sunless weather is associated with relatively high maximum temperatures on days with SW and W winds, and with relatively low maximum temperatures on the remaining days. This peculiarity of days with SW and W winds contributes to the negative correlation coefficients observed in Table 39. However the data contained in Table 40 shows that it is not the sole cause of these negative relationships.

TABLE 40. JANUARY: MEAN MAXIMUM TEMPERATURES PER HOURLY INTERVAL OF SUNSHINE DURATION ON DAYS WITH SW AND W WINDS, DURHAM OBSERVATORY, 1938 TO 1962
(degrees Fahrenheit)

Sunshine Duration (hourly intervals)

	0.0-0.9	1.0-1.9	2.0-2.9	3.0-3.9	4.0-4.9	5.0-5.9	6.0-6.9
SW	48	47	44	47	43	45	43
W	46	43	45	43	39	41	39

On days with SW winds in January the mean maximum temperature is 48°F when sunshine durations are from 0.0 to 0.9 hours. In both cases these data show an irregular fall in mean maximum temperature with increasing sunshine duration.

The remainder of this chapter examines the monthly variations in the relationships between sunshine duration and maximum temperature. These monthly accounts are designed to describe the limits of the periods during which the typical winter and summer relationships prevail. It examines separately the relationships observed on days with SW and NE winds since these were associated with the extreme tropical and polar conditions in the previous analyses.

B. MONTHLY VARIATIONS

1. SW WINDS

The relationships between sunshine duration and maximum temperature on days with SW winds are shown in Figure 27. The 12 scatter diagrams in Figure 27 refer to the individual months. The results of the numerical analyses of these scatter diagrams are contained in Table 41.

TABLE 41. SW WINDS: MONTHLY RELATIONSHIPS BETWEEN SUNSHINE DURATION AND MAXIMUM TEMPERATURE, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

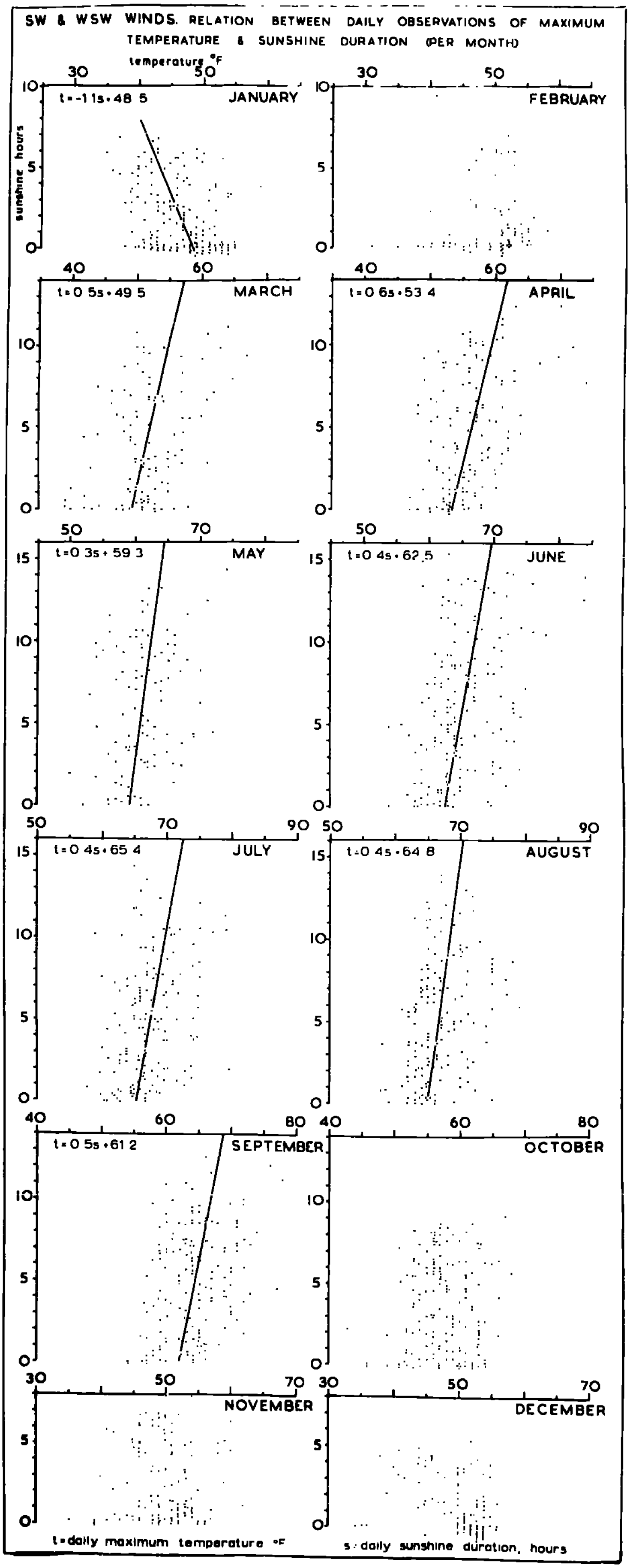
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
a.	-0.50	-0.08	+0.32	+0.25	+0.21	+0.33	+0.26	+0.32	+0.22	+0.10	-0.03	-0.11
b.	162	151	107	141	98	162	159	160	170	167	137	162
c.	1.0	/	0.5	0.6	0.3	0.5	0.5	0.3	0.5	/	/	/

a = coefficient of correlation

b = number of days

c = regression of maximum temperature upon sunshine duration (regression equation, Table 95)

FIG 27


SW & WSW WINDS. RELATION BETWEEN DAILY OBSERVATIONS OF MAXIMUM TEMPERATURE & SUNSHINE DURATION (PER MONTH)

These data indicate a two-fold subdivision of the year into winter and summer periods.

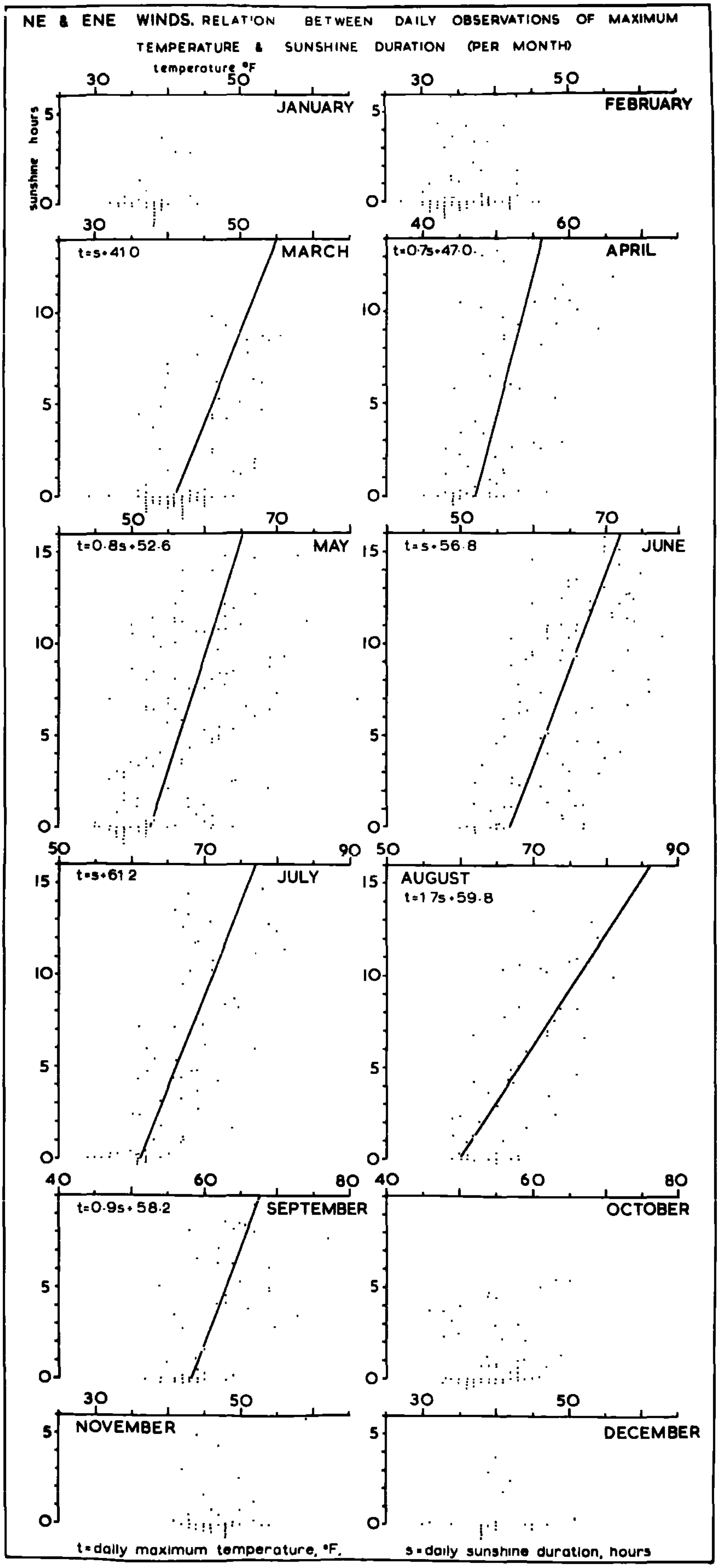
The winter period extends from October to February. Generally the correlation coefficients observed in the winter months are negligible but in January there is a significant negative correlation coefficient between these elements.

Summer extends from March to September and it is typified by low, significant positive correlations. During this summer period there are irregular monthly variations in both the correlation coefficients and the regressions of maximum temperature upon sunshine duration. However mid summer peaks in either of these statistics are absent from Table 41. The resultant relative uniformity during summer emphasises the abruptness of the transitions which occur between the two divisions of the year.

2. NE WINDS

Scatter diagrams relating sunshine durations and maximum temperatures observed on days with NE winds are shown in Figure 28 and the results of the numerical analyses of these are contained in Table 42.

FIG 28



NE & ENE WINDS. RELATION BETWEEN DAILY OBSERVATIONS OF MAXIMUM TEMPERATURE & SUNSHINE DURATION (PER MONTH)

t=daily maximum temperature, °F. s=daily sunshine duration, hours

TABLE 42. NE WINDS: MONTHLY RELATIONSHIPS BETWEEN SUNSHINE DURATION AND MAXIMUM TEMPERATURE, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	Mar.	Apr.	May	June	July	Aug.	Sept.
a.	+0.54	+0.44	+0.51	+0.62	+0.74	+0.71	+0.56
b.	81	60	119	94	64	51	45
c.	1.0	0.7	0.8	1.0	1.1	1.6	0.9

a = coefficient of correlation

b = number of days

c = regression of maximum temperature upon sunshine duration (regression equation, Table 94)

These data also suggest a two-fold subdivision of the year into a winter period extending from October to February and a summer period extending from March to September. In this case the contrast between these two periods is very pronounced. During the winter period the two elements are unrelated whereas in summer positive correlations of over 0.5 exist between them in almost all months.

However there are considerable variations in this oefficient and in the regression of maximum temperature upon sunshine duration in Table 42. The correlation coefficients are arranged in a fairly smooth curve which has a pronounced peak in July. This smoothness is lacking from the curve of regressions in Table 42 and in this ase a very sharp peak occurs in August.

CHAPTER 11

DISCUSSION

Daily maximum temperatures are partly determined by the surface temperatures of prevailing air masses and in this respect they are independent of sunshine duration.

However they are also determined by the warming and cooling processes which operate at the earth's surface. Each of these processes is affected by sunshine duration and, therefore, each encourages an association between sunshine duration and maximum temperature.

The surface warming and cooling processes are both accelerated during sunny periods since the absence of cloud increases the receipt of heat as short wave radiation and it increases the loss of heat as long wave radiation. The former process encourages a positive relationship and the latter encourages a negative relationship between sunshine duration and maximum temperature.

Initially this chapter discusses separately the general relationships between sunshine duration and the warming and cooling processes. Later these general relationships are applied in a discussion of the results obtained in this analysis.

A. GENERAL RELATIONSHIPS

1. WARMING PROCESSES

The principal warming process at the earth's surface is the absorption of short wave radiation. Monteith and Szeicz[1] have derived a 'heating coefficient' from the components of the radiation balance and Gold[2] has calculated the monthly mean daily temperature rise due to the absorption of short wave radition in Britain (Table 43).

TABLE 43. MONTHLY RELATIONSHIPS BETWEEN SCREEN TEMPERATURES AND SHORT WAVE RADIATION IN BRITAIN
From Gold

	Jan.	Feb.	Mar.	Apr.	May	June
a	40	70	100	140	175	180
b	9	12	15	17	19	20

	July	Aug.	Sept.	Oct.	Nov.	Dec.
a	165	150	115	80	40	30
b	19	18	16	13	9	8

a = daily receipts of heat used to raise screen temperatures; gram.cal.cm^2 (excludes heat received after 1500 hours, and that used for evaporation etc.)

b = mean daily increases in screen temperatures due to this heat supply;°F

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1. MONTEITH, J.L., and SZEICZ, G. The radiation balance of bare soil and vegetation. Quart.J.R.met.Soc., 87, 159, 1961.

2. GOLD, E., Maximum day temperatures and the tephigram. Prof. Notes, 63, 1933.

A close direct relationship exists between the daily magnitude of this warming and sunshine duration since the latter strongly controls the daily receipt of short wave radiation. Black, Boynthon and Prescott[1] have related daily sunshine duration and daily short wave radiation receipts in the following general terms: -

$$\frac{Q}{Q_A} = a + \frac{b\,n}{N}$$

Q = short wave radiation at earth's surface; gram. cal.cm^2.

Q_A = short wave radiation at earth's surface in absence of atmosphere

n = sunshine duration; hours

N = possible sunshine duration

a and b are constants

The values of the constants a and b depend on latitude. They may be arranged into seven latitudinal groups. In the latitude of the British Isles this formula has the following expression: -

$$\frac{Q}{Q_A} = 0.19 + \frac{0.567n}{N}$$

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[1] BLACK, J.N., BOYNTHON, C.W. and PRESCOTT, J.A., Solar radiation and the duration of bright sunshine. Quart.J.R.met.Soc., 80,231, 1954

It is tempting to presume that this formula may be applied to Monteith and Szeicz's heating coefficient or to Gold's data in Table 43 so that daily warming and sunshine are numerically related. Unfortunately this is prevented by a large number of instrumental and observational problems concerning these relationships. Five of the major problems are listed here since they also effect the relationships between sunshine duration and maximum temperature.

1. A proportion of the incoming short wave radiation is reflected from the surface and is not available in the warming process. Unfortunately the coefficient of reflection of short wave radiation varies according to time of day, surface wetness and vegetation type (Monteith and Szeicz[1]). Greatest losses occur when the elevation of the sun is low, when the surface is wet and over dense vegetation.
2. The intensity of the incoming short wave radiation varies greatly during the day. Therefore the heating powers of unit durations of sunshine also vary considerably. However Stagg[2] observed that short wave radia-

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[1] MONT~~M~~EITH, J.L. and SZEICZ, G. Op.cit., 1961

[2] STAGG, J.M., Solar radiation at Kew Observatory. Geophysical Memoirs, 86, 1950

tion intensities are relatively constant after the elevation of the sun exceeds 30°. Therefore, under cloudless conditions in June, there is a plateau of radiation intensity between 0900 hours and 1500 hours (the period during which the sun's elevation exceeds 30°). This plateau extends from 1000 hours to 1400 hours in March and it is absent in December.

3. The Campbell-Stokes sunshine recorder does not detect weak sunshine. The intensity of short wave radiation exceeds 0.2 cals.cm^{2}.min. before it burns the recording card.

4. This relationship ignores the effects of cloud type. Tait[1] noted that, although the basic cloud control upon short wave radiation is exercised through its amount, cloud elevations and types both have substantial subsidiary effects upon these relationships. For example, Tait found that the attenuation of radiation by a 5/10 cover of cumulus cloud is equivalent to that produced by a 6/10 cover of stratocumulus cloud or an 8/10 cover of altocumulus cloud. A 9/10 cover of stratus cloud has the same effect in this respect as a 10/10 cover of stratocumulus cloud.

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1. TAIT, G.W.C., The vertical temperature gradient in the lower atmosphere under daylight conditions. Quart.J.R.met.Soc., 75, 287, 1949

5. During periods of bright sunshine there are considerable variations in the intensity of radiation. These may be attributed to changes in the vapour pressure and concentration of pollutants in the air. Stagg[1] observed that 'on days of similarly cloudless sky and good visibility at the same time of year, one with an easterly air drift, the other with a westerly drift, the whole level of radiation could vary by 10 to 15 per cent.'

Therefore, although this warming process encourages a positive relationship between sunshine duration and maximum temperature it introduces many unknown quantities into the relationship.

2. COOLING PROCESSES

The two main surface cooling processes are long wave radiation and evaporation.

The relationships between cloud duration and long wave radiation are basically similar to those between cloud duration and short wave radiation. Cloud droplets act as black bodies with respect to the absorption of long wave radiation and so they seriously reduce the net loss of heat by this process.

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[1] STAGG, J.M. op.cit., 1950

This indirectly generates a negative relationship between sunshine duration and daily maximum temperature since the sunshine record inversely measures the daily duration of cloud cover. Cooling by the loss of long wave radiation is more intense during sunny than during cloudy periods.

Unfortunately this relationship also suffers from the effects of unknown quantities. For example, there is a pronounced diurnal variation in the intensity of long wave radiation and losses during unit periods of clear sky at mid day exceed those at other times. Additionally the effects of variations in cloud type, vapour pressure, concentration of pollutants complicate this relationship. The failure of the sunshine recorder to describe nocturnal cloud conditions is a further problem in this case. Fortunately this is relatively unimportant since maximum temperatures are usually attained in the daytime.

The second basic cooling process, evaporation, further complicates this relationship because it produces modifications in maximum temperature which are entirely unrelated to sunshine duration.

The effects of evaporation are most intense in winter and during wet periods. Penman[1] noted that from

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[1] PENMAN, H.C., Daily and seasonal changes in the surface temperatures of fallow soil at Rothamstead. Quart.J.R.met.Soc., 69, 1, 1943

October to March the evaporation from ground surfaces in Britain is approximately equal to that from open water and this fundamentally modifies the seasonal relationships between ground and screen temperatures. Between April and September ground temperatures are persistently greater than air temperatures. However from October to March there is equality between the two.

The remainder of Chapter 11 will apply these general considerations in a discussion of the results of this analysis.

3. DISCUSSION OF RESULTS

The basic variations in the relationships between sunshine duration and maximum temperature are two-fold since they are mainly functions of time of year and wind direction. The causes of each of these basic variations will be examined separately.

1. SEASONAL VARIATIONS

The year is divisible into two parts on the basis of these relationships. From March to September positive correlations prevail and from October to February the elements are either uncorrelated or they are negatively correlated. (Table 41 and Figure 28) The transitions between these summer and winter periods are, in most cases, abrupt. For example,on days with NE winds the correlation coefficients in March and September are +0.54 and +0.56 respectively, whereas in February and October they are +0.09 and +0.17 respectively. On days with SW winds the correlation coefficient in February is -0.08 while that of March is +0.32. The general contrast between these summer and winter periods is more readily explained than the abruptness of the transitions between the two periods.

This general contrast may be explained in terms of the seasonal variations in the ratio between daily receipts of short wave radiation and daily losses of long wave radiation. In the preceeding general discussion it was proposed that the process of warming by the absorption of shortwave radiation encourages a positive relationship while that of cooling by the loss of long wave radiation encourages a negative relationship between the two elements. Hence, in mid summer, when daily receipts of short wave radiation are relatively great, the two elements are likely to be positively related. In mid winter, daily losses of long wave radiation are relatively great and the two elements are likely to be negatively related. The relative durations of these periods probably depend on latitude. The summer period of positive correlation is likely to expand towards the equator and the winter period of negative correlation is likely to expand towards the poles.

In summer the results of the present analysis support this explanation since the period of positive relationship between the two elements coincides with that of maximum daily receipts of short wave radiation (Table 44).

TABLE 44. MONTHLY MEAN DAILY RECEIPTS OF SHORT WAVE RADIATION UPON A NORMAL SURFACE AT KEW, 1933 TO 1944, cals. cm^2.
After Stagg[1]

Jan.	Feb.	Mar.	Apr.	May	June
38	70	130	192	258	294
July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
245	233	181	108	49	36

This analysis suggests that positive relationships between sunshine duration and maximum temperature prevail when the mean daily receipt of short wave radiation exceeds a limit of between 110 and 130 cals. per cm^2.

However in winter the actual relationships between the two elements differ from those expected because negative correlations only occur on days with SW and W winds in January. From October to February the elements are usually uncorrelated. This lack of correlation probably

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[1] STAGG, J.M., op.cit., 1950

represents a state of balance between the small daily receipts of short wave radiation and the losses of long wave radiation. The results of this analysis suggest that a negative correlation only exists in winter when the loss of long wave radiation is increased by a rise of surface temperatures due to the influx of warm Tm or Pm(I) air masses.

The rapid changes in correlation coefficient observed between February and March, and between September and October may be caused by the effects of evaporation. Penman[1] observed that from October to March the evaporation from the land surface is almost equal to that from open water. This provokes a two-fold subdivision of the year into a winter period in which ground surface and screen temperatures are similar, and a summer period in which the former exceed the latter. More of the daily receipt of short wave radiation is available for surface heating in summer than in winter when a substantial proportion of this radiation is converted into latent heat of evaporation.

However the limits of Penman's winter period of excessive evaporation are not exactly similar to the period

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[1] PENMAN, H.C., _op.cit._, 1943

during which sunshine duration and maximum temperature are uncorrelated since the former extends into March.

2. VARIATIONS ACCORDING TO WIND DIRECTION

Significant variations in the relationship between the two elements are observed when the data are distinguished according to wind direction. In mid summer positive correlations are most pronounced with winds of the eastern group and with NW winds. For example in July the correlation coefficients exceed ~~40.7~~ + 0·7 on days with SE, NE and NW winds and they fall to ~~40.26~~ +0·26 on days with SW winds. In mid winter negative correlation coefficients are only observed on days with SW and W winds.

These contrasts are probably caused by variations in outgoing long wave radiation within air masses of different temperatures. Throughout the year the daily losses of long wave radiation are usually greater within warm than within cold air masses. This relatively rapid loss of long wave radiation encourages daily sunshine durations and daily maximum temperatures to be negatively correlated within warm air masses. Consequently, in mid winter negative correlation coefficients are most likely to occur on days with SW winds and in mid summer positive correlations will be most pronounced on days with NW, N and NE winds.

C. INTRA-MONTHLY CHANGES

This discussion has ignored the problem created by the intra-monthly changes in sunshine duration and maximum temperature. Within most months there are usually substantial changes in the daily means of each of these elements between the beginning and the end of the month.

Generally these changes are of the same sign and both sets of daily means either increase or decrease towards the end of the month. Between January and July these daily means increase, and between August and December they decrease during the month. In these cases a positive correlation is encouraged between the two elements by the intra-monthly changes. This effect is most pronounced in March and October when the seasonal changes are at a maximum.

However near the solstices the intra-monthly changes are of opposite signs because the seasonal regime of temperature lags slightly behind that of sunshine duration. During January the mean daily maximum temperature continues to fall while that of sunshine duration rises. The reverse is true in July. In these cases a negative correlation between the two elements is encouraged by the intra-monthly changes.

Two considerations appear to justify the neglect of this factor in the present analysis. The main variations in these relationships are seasonal and the peak contrasts are those between mid summer and mid winter when the intra-monthly changes in each element are negligible. Furthermore, the contrasts between days with different wind direction are unaffected by the intra-monthly changes.

CONCLUSION

This thesis has applied an unusual climatological analysis to three problems. The analysis may be termed 'two-dimensional' because it describes the mean variations of data according to time of year and daily wind direction. Many climatological analyses are one-dimensional since they only describe the seasonal variations of data.

The seasonal variations of most extra-tropical data are pronounced. These variations are thoroughly documented and their general causes are understood. However, this thesis has described large mean variations of data among days of different wind direction. Isolated examples recall these variations.

The mean maximum temperature observed on days with NE winds in February is almost 12°F less than that observed on days with SW winds in February. This range is over half that of monthly mean daily maximum temperatures at Durham Observatory. The mean sunshine duration observed on days with N winds in February is 2.9 hours less than that of days with W winds in February. This difference compares with a range of 4.5 hours between the mean daily sunshine durations of June and December at Durham Observatory.

This conclusion discusses the causes of the contrasts between the mean properties of days of different wind direction and the general significance of the two-dimensional analysis. It examines propositions that these contrasts are attributable to the properties of the air masses invading the British Isles and that the mean properties of days with a particular wind direction are controlled by the characteristics of the air masses which commonly arrive from that direction.

This is an important proposition since it implies that the two-dimensional analysis provides a simple method of describing the long~~er~~-term mean properties of air masses. Unfortunately, three basic problems are involved in this application of the analysis.

Firstly, it must be stressed that air mass movement is described by geostrophic rather than by surface winds. In areas of high relief surface winds may depart widely from geostrophic winds and, as a general rule over land surfaces, surface winds depart by an average of 30° from geostrophic winds.

The second problem is that in some cases different air masses approach the British Isles from the same direction. For example, Tm and Pm (Returning) air masses often arrive from the south west. The mean properties of days with SW winds are a function of the characteristics of these two unlike air masses.

A final problem is that the two-dimensional analysis ignors the effects of trajectory curvature upon air mass properties.

A. SIGNIFICANCE OF TWO-DIMENSIONAL ANALYSES

The two-dimensional analysis classifies days according to their monthly occurrence and their mean wind direction (page 30). Arbitrary units are used within this classification. The calendar month is the unit of time and wind directions are classified into eight directions. Consequently, all daily observations recorded during the 25-year period, other than those recorded on days of variable wind direction (page 31), are classified into one of 96 categories. The two-dimensional analysis describes the mean properties of each category.

Two components of the variations of data are therefore described by the analysis. This discussion of the significance of the two-dimensional analysis considers only that component determined by mean daily wind direction since the general causes of the seasonal variations are familiar. Initially the discussion considers the general contrasts between days of different mean wind direction.

The only rigid relationship between days included within a particular category is that on all such days the anemometer at Durham recorded winds from the same general direction. It is invalid to assert that the geostrophic wind directions over north east England were rigidly the same on all days within a particular category (page 173) or that the air masses invading north east England were the same on all such days (pages 172 to 173).

However, there is usually a close association between surface and geostrophic wind directions. This association is encouraged by the good exposure of Durham Observatory but it is weakened by the effects of local relief (page 173 b) and surface friction (page 173) upon surface wind directions.

This close association between the geostrophic and surface wind directions applies, of course, only to conditions above the weather station and the anemometer ignores regional variations in the geostrophic wind.

The geostrophic wind may be interpreted in terms of the movement of air masses and studies of the regional variations in its velocity allow the plotting of this movement. Consequently, the direction of the geostrophic wind above the weather station is a function of air mass movement above that station. This implies an association between air mass movement and recorded surface wind direction. This association is important since, in general, it is responsible for the contrasts between the mean properties of days with different wind direction. These contrasts are relatively great over the British Isles which tend to be invaded by very unlike air masses from different directions and classifications of British weather often rely heavily upon the contrasts between days of different wind direction (Lamb[1]).

Two important inferences may be derived from this association between surface wind direction and air mass movement. An initial implication, of specific interest to this discussion, is that the relationships described by two-dimensional analyses may be explained in terms of air mass characteristics. The mean properties of days with a particular wind direction are largely determined by the characteristics of the air masses which most commonly arrive from that direction. Chapter 8 associated most wind directions with particular air masses and utili~~s~~zed the results of the two-dimensional analysis to describe the mean rates of sunshine production within air masses.

A second inference to be derived from this association is that two-dimensional analyses can be utili~~s~~zed to describe

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[1] LAMB, H.H., Types and spells of weather around the year in the British Isles: annual trends, seasonal structure of the year, singularities. Quart.J.R.met.Soc., 76, 393, 1950

the mean properties of air masses. This is an important implication because it suggests a simple approach to the otherwise difficult problem of preparing long-term local and regional air mass climatologies.

For example, it is important to describe the mean January rainfall within Tm air masses over a long period at a particular station. Important inferences concerning the effects of relief upon Tm air could be derived from isohyet maps showing long-term mean January rainfalls from Tm air masses.

Unfortunately, geostrophic wind analysis is laborious and it is usually difficult to apply this analysis to periods of the order of 20 years. Equally laborious are the methods of synoptic climatology which attempt to describe the mean properties of days with a particular synoptic situation. Barry[1] restricted his classification of synoptic situations in north east Canada to a period of under two years. Shaw[2] described the origins of precipitation within particular synoptic situations over northern England during a five-year period and complained of the difficulty involved in extracting significant conclusions from such a small sample.

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1. BARRY, R.G., A note on the synoptic climatology of Labrador-Ungava. Quart.J.R.met.Soc., 86, 557, 1960

2. SHAW, E.M., An analysis of the origins of precipitation in Northern England, 1956-1960. Quart.J.R. met.Soc., 88, 539, 1962

The assumption that two-dimensional analyses can be used to describe the mean properties of air masses is important since mean daily wind directions are quickly extracted from the anemograph. Hence this analysis can be readily extended to long periods. Unfortunately, a number of problems are raised by this assumption. These problems seriously affect the validity of associating observed mean daily wind directions with particular air masses. This conclusion will examine these problems.

B. PROBLEMS

The main problems facing the application of the two-dimensional analysis arise from the fact that it ignores regional changes in wind direction. Consequently, the analysis fails to describe the curvature of air mass trajectories and it is unable to distinguish between unlike air masses which invade the British Isles from similar directions.

An additional problem~~s~~ arises from the departure of surface wind directions from geostrophic wind directions. This departure is likely to be significant over all land surfaces. In mountainous regions it is very pronounced. Unfortunately, this departure is not constant since it varies according to wind speed and air mass stability.

Finally, a number of problems are created by the choice of period of analysis and units of time and wind direction. The period of analysis may involve a climatic change and in this case the data included in each frequency distribution are not a random sample. The seasonal division of the year or the wind direction categories may be too course to detect significant relationships. This last group of problems is common to all climatological analyses.

1. AIR MASS CURVATURE

The properties of an air mass are partly controlled by the surface conditions within its source region and those of its trajectory. However, ~~they~~ these properties are also functions of the curvature of the trajectory. Air masses moving within the circulation of a depression are likely to differ greatly from air masses of similar origin circulating within an anticyclone. Furthermore, the properties of the air mass depend upon the radius of cyclonic or anticyclonic curvature. These modifications caused by curvature are extremely variable but it is useful to examine some of the mean contrasts between air masses of cyclonic and anticyclonic curvature.

Pm (Arctic) air masses arrive by a direct southward journey from the Arctic. They are characterised by relative coldness, dryness aloft and instability. Belasco[1] described the mean properties of two types of Pm (Arctic) air. P_1 circulates around a depression to the east or north east of the British Isles, while P_2 arrives within the circulation of an anticyclone to the west of the British Isles. These air masses both originate in the Arctic and traverse the Norwegian Sea. Their mean surface temperatures and vapour pressures are similar on arrival. The mean surface temperatures at Kew within P_1 and P_2 air masses in summer (July and August) are both 57°F, while in winter (January and February) these means are 34°F and 31°F respectively. In summer a mean surface vapour pressure at Kew of 11.4 mb in P_1 air compares with that of 11.2 mb in P_2 air.

However, the mean environmental lapse rates in P_2 air are at most levels lower than those in P_1 air. This reflects the contrast between dynamic heating in P_2 air and dynamic cooling in P_1 air. In winter this contrast is most pronounced (Table 44b).

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1. BELASCO, J.E., Characteristics of the air masses over the British Isles. Geophysical Mem., 87, 1952

TABLE 44b. MEAN LAPSE RATES OF TEMPERATURE IN P_1 AND P_2 AIR MASSES OVER KEW IN SUMMER AND WINTER (from Belasco[1])

	Summer		Winter	
Height (Kms)	P_1	P_2	P_1	P_2
5 - 6	4.2	4.2	4.4	4.4
4 - 5	3.9	3.9	4.3	4.2
3 - 4	3.7	3.4	4.2	4.1
2 - 3	3.3	3.3	4.0	3.7
1 - 2	3.5	3.4	3.9	3.6
0.5 - 1	4.1	3.7	3.8	3.0

N.B. Data refer to decrease in temperature (°F) per 1,000 feet.

Summer = July and August
Winter = January and February

Belasco described comparable mean contrasts between the cyclonic and anticyclonic subtypes of each of the remaining air masses. In general the mean surface temperatures and vapour pressures of the subtypes are similar but the mean environmental lapse rates in the cyclonic subtypes exceed those in the anticyclonic subtypes. Dynamic heating and cooling are likely to severely control the weather produced by an air mass. In cases of intense curvature the modification is extreme.

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1. BELASCO, J.E., op.cit., 1952

The problem reduces the two-dimensional analysis to a purely descriptive role. The analysis may describe the whole range of conditions produced by an air mass but it fails to distinguish between the conditions produced by the cyclonic and anticyclonic subtypes or between the varieties possessing various degrees of curvature. Consequently, there is usually no basis for interpreting, in terms of air mass properties, the relationships described by the two-dimensional analysis.

2. COINCIDENT TRAJECTORIES

In general the air masses which invade the British Isles arrive by unique trajectories. This is attributable to the location of the British Isles on the margin of Eurasia and in the mid-latitudes. Continental and maritime air masses tend to arrive from opposite directions as do polar and tropical air masses. Naturally the individual air mass trajectories are not rigidly defined and they overlap to a certain extent.

However, this overlapping is occasionally pronounced and the final parts of the trajectories of unlike air masses coincide. This mainly applies to those air masses which approach the British Isles along the general lines of the polar front and the continental margin.

South westerly airstreams over the British Isles are usually associated with invasions of Tm or Pm (Returning) air masses. The latter arrives after circulating around a deep depression to the west of the British Isles. Pm (Returning) air suffers serious modification during its prolonged maritime journey and, over the last part of its journey, it is usually advectively cooled. Nevertheless, there are important contrasts between Pm (Returning) and Tm air masses over the British Isles and these emerge from Belasco's accounts of the mean properties of these air masses over Kew. At the surface P_7 air (Belasco's classification of Pm (Returning) air) is cooler and drier than T_1 and T_2 air masses (Belasco's subtypes of Tm air). These contrast appear in Table 44c.

TABLE 44c. MEAN SURFACE TEMPERATURES AND VAPOUR PRESSURES IN P_7, T_1, and T_2 AIR MASSES OVER KEW IN SUMMER AND WINTER (from Belasco[1])

	MEAN SURFACE TEMPERATURE (degrees Fahrenheit)		MEAN SURFACE VAPOUR PRESSURE (millibars)	
Air Mass	Summer	Winter	Summer	Winter
P_7	65	47	15.6	9.2
T_1	66	51	17.1	10.9
T_2	68	50	17.6	10.3

N.B. Summer = July, August Winter = January, February

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[1] BELASCO, J.E., op.cit., 1952

However, the main differences between these air masses are aloft. For example, the mean environmental lapse rates in P_7 air exceed those in T_1 and T_2 air masses. (Table 44d) This is attributable to the relatively small modifications which P_7 air masses undergo in the middle and upper troposphere and to their cyclonic trajectories.

TABLE 44d. MEAN LAPSE RATES OF TEMPERATURE IN P_7, T_1 AIR MASSES OVER KEW IN SUMMER AND WINTER (from Belasco[1])

	SUMMER			WINTER		
Height (Km)	P_7	T_1	T_2	P_7	T_1	T_2
5 - 6	4.3	3.6	3.2	4.4	3.7	3.8
4 - 5	3.8	3.3	3.1	4.1	3.4	3.5
3 - 4	3.4	3.0	3.0	3.6	3.2	3.2
2 - 3	3.3	2.7	2.3	3.3	2.7	2.5
1 - 2	3.4	2.0	1.7	3.5	2.4	1.4
0.5 - 1	3.7	1.7	1.9	3.3	1.3	0.3

N.B. Data refer to decreases in temperature (°F) per 1,000 feet

Summer = July and August

Winter = January and February

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[1] BELASCO, J.E., <u>op.cit.</u>, 1952

North easterly and south easterly air streams over the British Isles are also associated with unlike air masses.

Air in north easterly air streams may have originated in the Arctic and traversed the Norwegian Sea, or it may have crossed the North Sea after originating in Eurasia. Belasco reported mean winter surface temperatures at Kew of 34°F and 29°F in P_1 (Pm (Arctic)) and A_1 (Pc) air masses respectively. The corresponding mean surface vapour pressures are 4.9mb in P_1 air and 4.1mb in A_1 air.

South and south easterly airstreams over the British Isles may be associated with Tc or Pc air masses. In winter the contrasts between these air masses are, of course, great.

3. SURFACE FRICTION; RELIEF

This conclusion is investigating the validity of the assumption that the mean properties of days with a particular wind direction are controlled by the characteristics of the air masses which commonly arrive from that direction.

An important objection to this assumption involves the fact that the anemometer does not record the local geostrophic wind. Surface friction causes winds to back with respect to the geostrophic wind direction. This effect is most pronounced over land surfaces and forecasters usually assume that this backing amounts to 30° over land surfaces and 10° over sea surfaces. Unfortunately, on individual occasions the backing may vary within wide limits. Marshall,[1] comparing corresponding geostrophic and surface wind directions at Kew, noted a surface wind backing of over 50° on 21% of occasions, a backing of 20° to 40° on 55% of occasions, and a veering of 20° to 40° on 2% of occasions. On only 16% of occasions was the surface wind within 10° of the geostrophic wind. The two-dimensional analysis deals with large groups of days and this may justify an application of a mean correction of 30° to convert surface into geostrophic wind directions.

However, in areas of pronounced relief the contrasts between surface and geostrophic wind directions is greater and more complex. The effects of relief are selective with respect to wind direction. A subjective, though detailed, impression of the effects of relief upon wind direction was ~~is~~ provided by Oliver[2] who described the deformation of vegetation in the Dale Peninsula. The survey suggests that within this small peninsula prevailing wind directions vary between 250° and 170°. Spurr[3] compared wind directions observed in the Llynfi Valley with those observed at Cardiff,

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[1] MARSHALL, W.A.L., Comparison of the wind recorded by the anemograph with the geostrophic wind. Professional Notes, 108, 1954

[2] OLIVER, J., Wind and vegetation in the Dale Peninsula. Field Studies, 1, 37, 1960

[3] SPURR, G., The channelling effects of a valley. Weather, 14, 270, 1959

and asserted that the valley is able to divert winds by 30° from the regional wind directions. Dines[1] compared corresponding surface and geostrophic wind directions observed at Valencia. He detected severe modifications of wind direction by neighbouring mountains. South east and south south west winds are usually backed by 40° to 50° with respect to geostrophic wind directions at Valencia. Manley[2] observed a tendency for the Wear Valley to cause east winds to locally set from the north east at Durham.

A graphical comparison of surface and geostrophic winds by McIntyre[3] is interesting since it may form a basis for correcting this effect of relief upon wind direction. McIntyre prepared scatter diagrams calibrated in terms of geostrophic wind direction and corresponding surface wind direction. This diagram shows that north west geostrophic winds are channelled into a west or south west direction through the Juan de Fuca Straits by the Olympic and Vancouver mountains.

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1. DINES, L.H.G., A comparison between the geostrophic wind, the surface wind, and the upper winds derived from pilot balloons, at Valencia Observatory, County Kerry. Professional Notes, 83, 1938
2. MANLEY, G., The Durham meteorological record, 1847 - 1940. Quart.J.R.met.Soc., 67, 363, 1941
3. McINTYRE,D.P., A technique of wind analysis and forecasting as applied to Victoria, British Columbia. Quart.J.R.met.Soc., 78, 247, 1952

In areas of simple relief, such as straight valleys or ridges the general effects of relief upon wind direction could be detected by a scatter diagram and eliminated. This correction must remain an approximation, however, because the magnitude of this relief control depends upon the speed of the wind and the stability of the air. Scorer[1] showed that the effects of relief upon wind direction are severe when there is a surface temperature inversion and negligible during periods of thermal convectivity.

A final problem concerns underexposure of the anemometer. A striking demonstration of the effects of underexposure was provided by Thomas[2] who observed that the anemometer at Lizard virtually ceased to function on occasions of north west winds. This was attributed to eddying to the lee of a row of houses.

Clearly the two-dimensional analysis is inapplicable in areas of high relief and in cases of under-exposed anemometers. In all land areas an average correction of 30° may profitably be applied to surface winds in order to convert these into geostrophic wind directions. Scatter diagrams, depicting corresponding surface and geostrophic wind directions recorded over a short period of time may be used to detect a recurring modification of wind direction by relief.

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1. SCORER, R.S., Mountain-gap winds; a study of surface wind at Gibraltar. Quart.J.R.met.Soc., 78,53,1952
2. THOMAS, M.J., Notes on the behaviour of the anemograph at Lizard. Professional Notes, 73, 1936

C. APPLICATIONS

The remainder of this conclusion examines applications of the two-dimensional analysis within air mass climatology, local climatology and local weather forecasting.

1. AIR MASS CLIMATOLOGY

The conclusion has examined three problems which seriously affect the application of the two-dimensional analysis within air mass climatology.

The general effects of relief upon wind direction can be detected and, occasionally, they may be satisfactorily eliminated. However, this is untrue of the problems created by the arrival of different types of air from similar directions since the two-dimensional analysis is unable to distinguish between these different air masses.

Consequently, relationships described by the analysis are functions of the properties of groups of air masses rather than single air masses. This is particularly true of wind directions associated with different types of air mass. However, it applies also to wind directions which are commonly associated with one air mass since the properties of the air mass are seriously modified by the curvature of its trajectory.

These problems reduce the two-dimensional analysis to a completely descriptive rôle. The relationships which it describes cannot be interpreted in terms of air mass properties despite the fact that they are functions of these properties. This was apparent in the second and third parts of this thesis. The analyses within these parts described wide variations in the frequencies of rates of sunshine production and in the associations between sunshine duration and maximum temperatures. However, the discussions of these variations invoked isolated controls rather than general air mass properties.

The advantage of the two-dimensional analysis is its simplicity. The classification of days according to mean wind direction is simple in comparison to classifications according to synoptic situation. Consequently, two-dimensional analyses can be extended over relatively long periods of time.

2. LOCAL CLIMATOLOGY

Many of the processes described by local climatology operate during periods with winds from a specific direction or range of directions. Processes involving the vertical displacement of air by relief and advective heat transfer frequently operate selectively with respect to wind direction. For example, the föhn wind process requires winds blowing across mountain ranges; low cloud and fog formed by advective cooling over relatively cool sea surfaces drifts inland during periods of onshore winds.

The two-dimensional analysis may be applied to these processes to provide an impression of their general effects over long periods of time. This is accomplished indirectly by applying the analysis to an element which is effected by the process and which acts as an index of that process. Advective cooling is responsible for relatively low temperatures, shallow environmental lapse rates, high relative humidities, fog and stratus cloud formation. Indices of advective cooling therefore include daily maximum temperature, environmental lapse rates in the turbulence layer, relative humidity, fog frequency, stratus cloud amount and sunshine duration.

The first part of this thesis contained an example of this application of the two-dimensional analysis to a local climatic problem. Sunshine duration and maximum temperature were used as indices of advective cooling. The analysis endeavoured to detect relatively low sunshine durations and maximum temperatures, attributable to this process, on days with winds of the eastern group in April, May and June.

There are usually intense regional variations in the character or magnitude of a local climatic phenomenon. These regional variations can be described by applying similar two-dimensional analyses to the records of a number of stations. The initial stages of this analysis are laborious but the procedure can be simplified by restricting the analysis to days with wind directions associated with the phenomenon.

For example, the regional variations in the effects of the haar upon daily maximum temperatures may be examined by applying the two-dimensional analysis to the records of a number of stations in north east England. These analyses may be restricted to days with winds of the eastern group in late spring and early summer. The results contained in this thesis may be included in this regional study.

Similarly, two-dimensional analyses may be applied to a traverse of stations across the Penines to provide a long~~er~~-term impression of the effects of orographic uplift and subsidence on the weather during days with westerly and easterly winds.

3. LOCAL WEATHER FORECASTING

A merit of the two-dimensional analysis is that it can be extended to long periods of time since days are readily classified according to their mean wind direction. The parameters describing the properties of each group of days are likely to be highly significant since they are derived from large samples. Parameters such as the extreme maximum and minimum, the mean and the standard deviation of each frequency distribution are quickly calculated from a simple programme and arranged in tabular form. Appendix 2 contains a series of tables describing the parameters of the frequency distributions obtained by this analysis.

These tables may assist the local weather forecaster.[1] A rapid reference to such tables on a day with a particular wind direction in an individual month indicates the extreme values achieved under these circumstances during a given period by an element. Comparisons of the means and the standard deviations indicate the probabilities with which the value of the element will occur between given limits.

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1. Barnes prepared a 'climatological frequency distribution diagram' to aid local forecasting. This is a scatter diagram, calibrated in terms of wind direction and corresponding wind speed, depicting variations in the frequency or amount of rain, cloud and wind.

   BARNES, F.A., Shelter and exposure in west Anglesey. Weather, 4, 110 and 183, 1949

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APPENDIX 1

FORMULAE

the formulae used within this thesis are listed below.

A. STANDARD DEVIATION

$$s = \sqrt{\frac{\sum ft^2}{\sum f}}$$

$s =$ standard deviation
$t =$ individual deviation from the actual mean
$f =$ frequency of individual values

or

$$s = c\sqrt{\frac{\sum ft^2}{\sum f} - \left(\frac{\sum ft}{\sum f}\right)^2}$$

$s, f,$ = as above
c = cell interval
t = individual deviation from assumed mean

B. SKEWNESS (page 37)

$Sk =$ skewness

$$Sk = \frac{\bar{t}_+}{\bar{t}_-} \times 100$$

$\bar{t}_+ =$ mean deviation above the mean

$\bar{t}_- =$ mean deviation below the mean

C. WEIGHTED OVERLAPPING MEAN (page 107)

This formula was applied during the preparation of the adjusted frequency distributions of daily sunshine duration. The frequency (f_i) of each duration was weighted by an amount depending upon the frequencies (f_{i+1}, f_{i-1}) of the adjacent values.

$$\bar{f} = \frac{(f_{i-1} + 2f_i + f_{i+1})}{4}$$

$\bar{f}$ = weighted frequency

D. COEFFICIENT OF CORRELATION

$$r = \frac{\frac{1}{n} \sum (a - \bar{a})\ (b - \bar{b})}{S_a,\ S_b}$$

r = coefficient of correlation

n = number of pairs of observations

$\bar{a}$ = mean maximum temperature

$\bar{b}$ = mean sunshine duration

a, b = corresponding individual daily observations of maximum temperature and sunshine duration

S_a = standard deviation of maximum temperature

S_b = standard deviation of sunshine duration

The correlation coefficients were tested by Student's 't' test.

E. LINEAR REGRESSION FOR ONE VARIABLE (page 103)

The 'mean slopes' of the adjusted frequency distributions of daily sunshine duration were expressed as linear regressions of frequency upon duration.

$$y = \frac{\sum (a - \bar{a})(b - \bar{b})}{\sum (a - \bar{a})^2}$$

y = decrease in frequency per unit increase in duration

$\bar{a}$ = mean duration

$\bar{b}$ = mean frequency

a, b = corresponding individual durations and frequencies

E. LINEAR REGRESSION FOR TWO VARIABLES (page 144)

$$a - \bar{a} = r \frac{S_a}{S_b} (b - \bar{b})$$ symbols as in D

TABLES

TABLE 45. DAILY MEAN WIND DIRECTIONS: MEAN FREQUENCIES PER MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
Jan.	1.4	1.2	0.7	1.5	6.1	6.6	4.8	2.6
Feb.	2.2	2.3	0.7	0.7	4.7	6.1	4.0	2.5
Mar.	2.6	3.2	2.0	2.1	5.1	4.5	3.5	2.3
April	4.5	2.4	1.2	1.2	3.6	5.6	3.9	1.6
May	6.9	5.0	1.5	1.4	3.4	4.0	2.0	1.0
June	3.9	3.8	0.7	0.8	2.7	6.9	3.0	1.6
July	3.0	2.6	0.6	1.0	3.5	6.5	4.3	2.0
Aug.	3.8	2.1	1.0	1.2	4.6	6.1	4.4	1.8
Sept.	2.5	1.8	0.4	0.9	6.1	7.0	4.1	2.4
Oct.	2.0	2.2	1.3	1.4	7.6	6.7	3.3	2.3
Nov.	1.8	1.4	1.4	1.3	6.6	5.6	4.4	3.2
Dec.	1.6	0.9	0.9	1.7	7.7	6.7	4.8	2.6

N.B. Data not corrected for varying durations of months.

TABLE 46. JANUARY: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
9-	.	.	.	.	.	.	1	.
8-	.	.	.	.	.	.	.	.
7-	.	.	.	.	.	.	.	.
6-	.	.	.	.	1	.	.	.
5-	.	.	.	.	1	4	1	.
4-	.	.	.	.	2	7	2	.
3-	.	.	.	.	1	7	6	.
2-	.	.	.	.	1	9	6	.
1-	.	.	.	.	3	10	7	1
50-	.	.	.	.	7	11	3	1
9-	1	.	.	1	8	13	5	2
8-	.	.	.	.	7	8	4	3
7-	.	1	.	.	8	13	4	2
6-	.	.	.	2	8	11	4	3
5-	.	.	.	2	4	9	8	3
4-	2	1	.	1	5	8	5	1
3-	5	2	1	.	6	13	8	3
2-	3	1	.	2	8	12	4	4
1-	2	1	.	1	9	6	5	8
40-	2	1	1	2	5	9	5	4
9-	5	5	3	3	10	5	11	4
8-	1	7	2	1	11	3	4	6
7-	6	3	2	2	8	2	6	3
6-	2	2	2	3	8	1	4	7
5-	3	1	2	4	5	1	1	3
4-	2	1	2	3	6	.	5	3
3-	1	2	1	4	4	1	2	1
2-	.	1	.	4	2	1	2	2
1-	.	.	1	1	2	.	3	.
30-	1	.	.	1	1	.	3	1
9-	.	.	.	.	.	.	2	.
8-	.	.	.	.	2	.	1	.
7-	.	.	.	.	.	.	.	.
6-	.	.	.	.	1	.	.	.

TABLE 47. FEBRUARY: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
9-	.	.	.	.	.	2	.	.
8-	.	.	.	.	.	1	.	.
7-	.	.	.	.	.	.	.	.
6-	.	.	.	.	1	4	.	.
5-	.	.	.	.	3	9	4	.
4-	.	.	.	.	2	6	5	1
3-	.	.	.	.	5	8	3	1
2-	.	.	.	.	4	17	5	.
1-	.	.	.	.	4	20	4	1
50-	.	.	.	.	6	10	9	2
9-	1	.	.	.	4	10	6	1
8-	1	.	.	.	7	5	10	2
7-	1	.	.	.	3	15	10	5
6-	1	1	.	.	5	7	2	4
5-	1	1	.	2	10	8	5	3
4-	4	.	.	1	3	5	3	3
3-	3	5	2	.	9	6	4	2
2-	1	5	1	3	7	5	2	.
1-	4	1	2	2	6	3	4	6
40-	.	1	1	1	4	4	5	10
9-	6	5	1	2	5	3	2	7
8-	5	5	1	1	4	1	5	2
7-	5	3	.	1	1	2	5	5
6-	6	4	2	2	3	.	3	2
5-	4	6	2	1	4	.	4	2
4-	4	8	1	.	8	1	.	1
3-	2	7	1	1	6	.	.	1
2-	3	1	2	.	2	.	.	.
1-	.	3	1	.	2	1	.	.
30-	2	1	.	.	.	.	.	1
9-	.	.	.	1	.	.	.	.
8-	.	.	.	.	.	.	.	.
7-	.	1	.	.	.	.	.	.

TABLE 48. MARCH: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
8-	.	.	.	.	1	.	.	.
7-	.	.	.	.	.	1	.	.
6-	.	.	.	.	.	.	.	1
5-	.	.	.	.	1	1	.	.
4-	.	.	.	.	2	1	.	.
3-	1	.	.	.	.	1	1	.
2-	.	.	.	.	.	.	1	.
1-	.	.	.	.	4	3	.	.
60-	.	.	.	.	.	4	1	1
9-	.	.	1	.	4	1	1	1
8-	1	.	.	1	1	5	2	1
7-	.	.	.	1	5	12	5	1
6-	2	.	1	1	5	5	3	1
5-	2	.	.	.	5	8	4	1
4-	.	1	1	3	5	8	9	.
3-	2	3	.	2	9	10	6	3
2-	.	4	1	2	10	7	6	2
1-	1	2	1	1	8	11	10	1
50-	3	2	1	2	5	8	6	1
9-	2	2	1	3	8	5	5	3
8-	2	3	.	3	5	5	7	2
7-	4	2	2	2	6	2	3	2
6-	3	6	4	2	5	3	1	2
5-	9	5	3	3	5	.	2	4
4-	3	4	1	2	7	3	4	2
3-	8	4	2	2	6	2	3	3
2-	7	8	6	2	4	3	1	5
1-	4	5	4	3	5	.	1	5
40-	3	7	8	4	1	2	.	4
9-	1	6	2	5	3	2	2	1
8-	4	4	3	.	1	.	2	2
7-	.	8	2	4	2	.	.	1
6-	1	3	.	2	3	.	.	2
5-	3	.	2	1	1	.	2	2
4-	.	.	3	.	.	.	1	.
3-	.	.	1	.	.	.	.	1
2-	.	1	.	1	.	.	.	1
1-	.	.	.	.	.	.	.	1
30-	.	.	.	.	.	.	.	.
9-	.	1	.	.	.	.	.	.

TABLE 49. APRIL: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
5-	.	.	.	.	1	.	.	.
4-	.	.	.	.	.	1	.	.
3-	.	.	.	.	1	.	.	.
2-	.	.	.	.	.	1	.	.
1-	.	.	.	.	1	.	.	.
70-	.	.	.	1	.	3	.	.
9-	.	.	.	.	1	.	.	.
8-	.	.	.	.	1	.	1	.
7-	.	.	.	1	1	1	2	.
6-	.	1	.	.	2	.	.	1
5-	.	.	.	2	2	.	1	.
4-	1	1	.	.	.	2	1	1
3-	.	.	.	1	2	4	1	.
2-	1	.	1	2	4	4	4	1
1-	2	1	.	1	2	8	2	.
60-	1	1	.	2	4	7	4	.
9-	2	2	.	.	5	5	5	1
8-	3	3	.	2	9	11	4	1
7-	2	1	2	.	5	12	5	1
6-	4	2	2	1	6	15	7	4
5-	9	2	1	2	7	11	7	2
4-	4	.	1	1	8	10	11	2
3-	7	3	2	1	3	13	10	1
2-	3	2	2	.	5	10	8	2
1-	9	7	.	3	2	6	6	3
50-	10	4	3	2	4	6	8	2
9-	9	4	4	1	4	4	7	1
8-	5	4	2	2	.	3	2	.
7-	9	4	2	1	3	2	.	3
6-	7	2	1	1	3	.	1	3
5-	8	6	1	3	1	.	1	2
4-	5	6	1	.	.	.	.	6
3-	3	3	1	.	2	.	.	3
2-	5	1	1	1	1	.	.	.
1-	.	.	1	.	.	.	.	.
40-	1	1	.	.	.	.	.	.
9-	2	.	2	.	.	.	.	.
8-	.	.	.	.	.	.	.	.
7-	.	.	.	.	.	.	.	.
6-	1	.	.	.	.	.	.	.

TABLE 50. MAY: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
1-	.	1	.	.	.	.	.	.
80-	1	.	.	.	.	.	.	.
9-	.	.	.	.	.	.	.	.
8-	.	.	.	.	.	.	.	.
7-	.	.	.	.	.	.	.	.
6-	.	.	.	.	.	.	.	.
5-	1	.	.	.	1	.	.	.
4-	.	1	.	.	2	2	.	.
3-	1	1	.	.	.	.	.	.
2-	1	.	.	.	1	1	.	1
1-	1	1	.	1	.	1	1	1
70-	4	1	1	.	2	2	.	.
9-	3	4	.	1	2	2	2	1
8-	5	.	.	.	3	2	2	.
7-	2	3	1	2	8	5	4	.
6-	7	1	.	1	2	5	.	.
5-	1	1	2	.	1	6	1	.
4-	3	6	1	1	3	5	1	1
3-	7	7	1	2	6	6	4	1
2-	3	6	5	1	7	8	4	.
1-	3	8	.	1	4	13	2	3
60-	6	5	4	2	8	8	5	4
9-	11	2	2	2	6	10	4	.
8-	5	4	3	2	7	6	1	3
7-	6	6	1	.	7	6	2	.
6-	4	8	1	3	4	5	5	.
5-	6	6	4	2	4	1	3	1
4-	9	2	2	2	.	4	3	.
3-	10	7	1	6	1	1	2	.
2-	9	10	.	1	2	1	2	1
1-	12	5	1	2	1	.	1	1
50-	12	5	.	2	1	1	.	1
9-	9	10	2	1	.	.	.	2
8-	8	6	2	.	1	.	.	2
7-	5	4	1	.	.	.	1	.
6-	4	1	.	.	.	.	.	.
5-	7	2	.	.	.	.	.	.
4-	3	.	.	.	.	.	.	.
3-	2	.	1	.	.	.	.	.
2-	.	.	.	.	.	.	1	.
1-	.	.	1	.	.	.	.	.

TABLE 51. JUNE: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
4-	.	.	.	.	.	2	1	.
3-	.	.	.	.	2	.	.	.
2-	.	.	.	.	.	.	.	1
1-	.	.	.	.	.	1	.	1
80-	2	.	.	.	3	.	.	1
9-	.	.	.	2	.	.	.	.
8-	1	1	1	1	2	1	.	.
7-	.	.	.	1	1	.	.	.
6-	.	2	.	.	.	3	.	1
5-	2	1	1	1	.	1	2	.
4-	1	2	.	.	1	4	.	.
3-	3	5	1	.	.	5	4	1
2-	2	4	.	.	1	5	2	1
1-	4	3	1	.	3	7	1	1
70-	2	5	2	4	1	8	5	2
9-	4	2	1	.	4	6	1	.
8-	2	2	1	.	3	3	5	2
7-	1	3	.	2	7	13	3	2
6-	1	7	1	3	2	10	4	1
5-	5	6	1	1	6	11	9	4
4-	4	8	.	.	7	18	6	3
3-	7	.	.	.	5	22	10	1
2-	5	7	.	.	2	20	6	.
1-	8	3	.	.	5	8	4	2
60-	2	4	.	.	4	6	3	3
9-	9	2	.	.	3	10	3	1
8-	4	5	3	2	2	4	3	2
7-	3	5	.	1	3	2	1	1
6-	5	4	1	1	.	1	.	1
5-	3	4	.	.	.	.	1	.
4-	3	2	1	.	.	2	.	2
3-	3	1	1	1	.	.	.	2
2-	2	5	.	.	.	.	.	.
1-	3	1	.	.	.	.	.	2
50-	1	1	1	.	.	.	.	1
9-	3	.	.	.	.	.	1	.
8-	1	.	.	.	.	.	.	.
7-	.	.	1	.	.	.	.	.
6-	1	.	.	.	.	.	.	.
5-	1	.	.	.	.	.	.	.

TABLE 52. JULY: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
3-	.	.	.	.	.	.	1	.
2-	1	.	.	.	.	1	2	.
1-	1	1	.	1	1	.	.	.
80-	1	1	.	.	1	2	.	.
9-	.	1	.	.	.	2	.	1
8-	.	1	.	.	1	.	.	2
7-	.	2	.	.	1	1	1	1
6-	3	.	.	.	2	.	3	3
5-	1	1	.	1	2	8	1	1
4-	1	2	1	1	4	6	4	1
3-	.	1	1	1	4	3	3	.
2-	2	1	1	1	4	5	1	1
1-	2	3	1	1	3	7	5	3
70-	4	2	1	3	8	10	6	.
9-	1	5	.	1	3	11	5	2
8-	8	4	2	3	10	12	7	2
7-	7	6	2	2	7	23	16	2
6-	2	4	.	1	7	20	10	1
5-	3	1	.	3	6	16	10	3
4-	4	4	4	1	7	8	9	10
3-	1	3	1	2	7	12	3	2
2-	7	6	.	1	6	5	10	2
1-	10	8	.	.	.	5	1	5
60-	5	2	.	1	3	4	3	3
9-	3	.	.	.	.	1	4	3
8-	3	1	1	.	.	1	2	.
7-	1	2	.	.	.	.	.	2
6-	1	1	.	.	.	.	.	.
5-	1	1	.	.	.	.	1	1
4-	2	1	.	.	.	.	.	.

TABLE 53 AUGUST: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
4-	.	.	1	.	.	.	.	.
3-	.	.	.	.	.	.	.	.
2-	.	.	.	.	.	.	.	.
1-	.	1	.	.	.	.	.	.
80-	1	.	.	.	.	.	.	1
9-	1	1	1	2	2	1	.	.
8-	.	1	.	1	1	1	1	1
7-	1	1	.	1	2	2	2	.
6-	.	4	1	.	1	.	2	.
5-	2	1	.	2	5	5	.	1
4-	2	1	.	.	5	3	.	.
3-	2	3	1	2	4	2	3	.
2-	4	3	2	1	6	6	2	1
1-	5	1	2	2	3	6	3	1
70-	3	1	1	.	8	9	5	2
9-	3	2	.	1	9	9	6	3
8-	6	6	.	2	12	9	7	1
7-	6	3	.	2	10	15	11	1
6-	4	3	1	3	15	15	14	2
5-	.	4	3	2	4	26	14	8
4-	9	2	.	1	9	13	10	1
3-	8	1	2	3	3	15	12	5
2-	5	4	1	.	3	11	8	3
1-	7	3	2	1	6	3	1	3
60-	8	3	1	2	3	.	6	3
9-	4	3	2	1	3	1	2	2
8-	3	.	3	1	.	1	.	1
7-	4	.	.	.	.	.	1	3
6-	5	.	.	.	.	.	.	2
5-	.	.	.	.	.	.	.	.
4-	.	.	.	.	.	.	.	1
3-	1	.	.	.	.	.	.	.

TABLE 54. SEPTEMBER: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
1-	.	.	.	.	2	.	.	.
80-	.	.	.	.	.	.	.	.
9-	1	.	.	.	.	.	.	.
8-	1	.	.	.	.	1	.	1
7-	.	1	.	.	.	1	.	.
6-	.	.	.	.	1	1	.	.
5-	.	.	.	.	2	.	.	1
4-	.	.	.	.	4	1	1	1
3-	.	1	.	2	1	2	3	.
2-	1	.	1	.	3	7	1	1
1-	.	.	.	1	2	7	3	.
70-	.	1	.	2	7	6	2	.
9-	1	1	.	.	7	9	1	.
8-	1	.	1	1	11	4	6	.
7-	1	2	.	.	7	9	4	1
6-	3	2	.	1	7	12	8	.
5-	4	2	.	3	13	17	5	3
4-	2	5	.	3	14	22	4	2
3-	3	4	2	.	8	17	13	6
2-	7	3	.	1	15	9	10	8
1-	5	.	1	4	7	6	6	3
60-	4	3	3	2	15	13	2	3
9-	4	5	2	1	10	15	11	4
8-	9	3	1	.	7	6	6	5
7-	3	4	.	.	2	7	4	5
6-	1	3	.	.	2	2	2	3
5-	3	1	.	1	3	.	4	5
4-	5	3	.	1	.	1	3	4
3-	1	.	.	.	1	.	1	2
2-	1	1	.	.	.	.	.	1
1-	.	.	.	.	.	.	.	.
50-	.	.	.	.	.	.	.	.
9-	.	.	.	.	1	.	.	.
8-	.	.	.	.	.	.	.	.
7-	1	.	.	.	.	.	.	.
6-	1	.	.	.	.	.	.	.

TABLE 55. OCTOBER: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
4-	.	.	.	.	1	.	.	.
3-	.	.	.	.	1	.	.	.
2-	.	.	1	.	1	.	1	.
1-	.	.	.	.	.	.	.	.
70-	.	.	.	.	.	.	.	.
9-	.	.	.	.	1	.	1	1
8-	1	.	.	.	.	1	1	.
7-	.	.	.	.	1	1	.	.
6-	.	.	1	.	4	3	.	.
5-	.	1	.	.	5	1	3	.
4-	.	1	1	1	4	6	4	.
3-	.	1	1	1	8	14	1	.
2-	1	1	.	.	5	7	1	1
1-	.	2	.	1	10	12	3	1
60-	3	2	2	2	14	10	10	1
9-	.	4	1	3	13	10	5	.
8-	1	5	.	2	16	14	5	4
7-	2	2	1	3	16	17	2	2
6-	2	3	2	7	14	20	10	2
5-	4	6	3	3	20	11	9	2
4-	3	6	2	3	12	10	6	3
3-	6	3	2	.	12	13	4	5
2-	9	3	3	.	8	8	2	7
1-	6	4	2	1	8	4	3	4
50-	4	3	2	2	8	.	2	5
9-	3	2	4	.	1	2	3	6
8-	2	3	3	1	.	1	4	2
7-	2	1	2	3	1	.	.	1
6-	.	1	.	1	3	2	1	3
5-	1	2	.	.	.	.	1	5
4-	.	.	.	.	2	.	.	.
3-	.	.	.	.	.	1	.	.
2-	.	.	.	.	.	.	.	.
1-	.	.	.	.	.	.	.	1

TABLE 56. NOVEMBER: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
6-	.	.	.	.	1	.	.	.
5-	.	.	.	.	.	.	.	.
4-	.	.	.	.	.	.	.	.
3-	.	.	.	.	.	1	.	.
2-	.	.	.	.	2	1	.	.
1-	.	.	.	.	.	2	.	.
60-	.	.	.	.	.	1	.	.
9-	.	1	.	.	2	4	.	.
8-	.	.	.	.	3	3	1	.
7-	.	.	.	.	3	3	5	.
6-	1	.	1	.	4	4	1	1
5-	1	.	.	2	6	4	5	2
4-	.	1	1	1	5	11	4	1
3-	.	1	1	1	5	11	5	1
2-	5	2	.	2	13	10	1	2
1-	2	.	.	3	16	12	7	3
50-	1	3	1	2	15	9	10	7
9-	6	2	1	2	12	13	14	5
8-	.	5	.	1	11	9	9	10
7-	9	3	1	7	13	5	7	13
6-	3	4	3	2	9	12	7	6
5-	5	4	2	4	12	9	6	5
4-	4	3	1	2	13	2	5	9
3-	2	3	1	2	3	2	6	2
2-	2	2	1	.	4	3	4	3
1-	1	1	2	1	.	2	1	4
40-	1	.	.	.	3	1	2	2
9-	.	.	.	.	2	4	4	3
8-	.	.	.	.	1	.	5	1
7-	.	.	.	.	1	.	.	.
6-	.	.	.	.	2	.	.	.
5-	1	.	.	.	2	1	.	.
4-	.	.	.	.	1	.	2	1
3-	.	.	.	.	.	.	.	.
2-	.	.	.	.	.	.	.	.
1-	1	.	.	.	.	.	.	.

TABLE 57 DECEMBER: FREQUENCY DISTRIBUTIONS OF DAILY MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

degrees Fahrenheit	N	NE	E	SE	S	SW	W	NW
8-	.	.	.	.	1	.	.	.
7-	.	.	.	.	.	.	.	.
6-	1	.	.	.	2	3	.	1
5-	.	.	.	.	3	6	1	.
4-	.	.	.	.	1	13	3	.
3-	.	.	.	.	6	14	5	.
2-	1	.	1	.	4	12	1	1
1-	.	1	.	.	9	17	6	1
50-	1	.	.	4	6	16	11	2
9-	.	.	1	2	13	9	6	1
8-	.	.	1	4	15	9	5	2
7-	3	1	3	.	12	7	7	2
6-	1	.	1	6	11	12	10	4
5-	3	2	4	2	10	11	4	5
4-	3	1	2	4	6	14	6	3
3-	3	1	2	1	13	3	12	3
2-	1	1	2	1	18	5	6	3
1-	3	1	1	5	13	6	7	7
40-	2	4	.	2	11	5	4	5
9-	1	2	2	1	10	2	8	5
8-	3	.	1	2	5	.	7	3
7-	6	5	.	3	3	.	5	8
6-	2	.	.	2	9	1	2	2
5-	6	.	.	.	3	1	1	3
4-	.	2	1	.	5	1	2	.
3-	.	.	.	3	1	1	1	2
2-	.	.	.	.	.	.	.	1
1-	.	1	.	.	3	.	.	.
30-	1	1	.	.	.	.	.	1

TABLE 58. DAILY MAXIMUM TEMPERATURE: MEANS PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962
(degrees Fahrenheit)

	N	NE	E	SE	S	SW	W	NW
Jan.	39.0	38.3	36.7	37.3	41.2	46.3	42.6	40.3
Feb.	38.3	36.7	37.1	39.3	43.3	48.6	45.8	41.8
Mar.	44.9	43.0	42.4	44.8	49.5	52.6	50.0	45.0
April	49.8	50.0	49.4	54.6	56.0	56.2	54.8	50.7
May	55.8	56.7	56.9	57.5	61.3	61.5	59.4	57.2
June	61.5	63.4	63.9	67.3	66.2	65.2	65.0	63.6
July	65.1	66.2	67.1	68.2	68.0	67.6	66.9	66.0
Aug.	64.7	67.8	66.3	68.0	67.9	66.8	66.0	64.1
Sept.	60.4	61.3	62.9	64.0	64.2	64.3	62.7	60.2
Oct.	53.0	54.2	54.1	55.2	57.0	57.5	56.6	51.9
Nov.	46.7	47.1	46.7	48.0	48.7	50.1	47.6	46.6
Dec.	40.8	39.6	43.9	42.8	44.1	48.2	44.5	41.4

TABLE 59. DAILY MAXIMUM TEMPERATURE: ANOMALIES[1] PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

(degrees Fahrenheit)

	N	NE	E	SE	S	SW	W	NW
Jan.	-3.1	-3.8	-5.4	-4.8	-0.9	+4.2	+0.5	-1.8
Feb.	-5.2	-6.8	-6.4	-4.2	-0.2	+5.1	+2.3	-1.7
March	-2.5	-4.4	-5.0	-2.6	+2.1	+5.2	+2.6	-3.0
April	-3.5	-3.3	-3.9	+1.3	+2.7	+2.9	+1.5	-2.6
May	-2.3	-1.4	-1.2	-0.6	+3.2	+3.4	+1.3	-0.9
June	-2.8	-0.9	-0.4	+3.0	+1.9	+0.9	+0.7	-0.7
July	-1.8	-0.7	+0.2	+1.3	+1.1	+0.7	0	-0.9
Aug.	-1.7	+1.4	-0.1	+1.6	+1.5	+0.4	-0.4	-2.3
Sept.	-2.5	-1.6	0	+1.1	+1.3	+1.4	-0.4	-2.7
Oct.	-2.9	-1.7	-1.8	-0.7	+1.1	+1.6	+0.7	-3.8
Nov.	-1.5	-1.1	-1.5	-0.2	+0.5	+1.9	-0.6	-1.6
Dec.	-3.6	-4.8	-0.5	+0.3	-0.3	+3.8	+0.1	-3.0

[1] see page 54

TABLE 60. DAILY MAXIMUM TEMPERATURE: STANDARD DEVIATION PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

(degrees Fahrenheit)

	N	NE	E	SE	S	SW	W	NW
Jan.	3.5	3.4	2.9	4.8	6.5	3.8	6.3	4.7
Feb.	4.6	3.8	4.1	4.3	6.5	5.2	5.6	5.3
March	5.7	5.3	5.8	6.3	7.0	5.5	5.9	6.6
April	5.3	6.8	5.5	7.2	6.9	6.6	4.5	6.3
May	7.7	7.2	6.7	6.2	5.2	5.7	5.9	7.5
June	7.6	6.9	8.8	7.7	6.5	5.7	4.7	8.4
July	6.5	6.1	5.3	5.3	4.6	6.3	4.8	5.7
Aug.	5.8	5.7	6.8	6.4	4.4	4.3	3.8	6.1
Sept.	5.8	5.5	3.9	5.0	5.2	6.7	4.7	5.8
Oct.	4.1	4.8	5.5	4.6	5.7	4.4	5.8	5.0
Nov.	4.4	3.9	4.9	3.6	5.1	5.2	5.3	3.2
Dec.	5.4	4.6	3.5	5.3	5.9	6.4	5.4	5.1

TABLE 61. DAILY MAXIMUM TEMPERATURE: SKEWNESS[1] PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

(percentage)

	N	NE	E	SE	S	SW	W	NW
Jan.	107	142	75	147	126	95	105	105
Feb.	134	118	115	88	107	73	68	144
March	105	121	161	98	95	87	77	159
April	98	121	115	105	102	139	121	100
May	124	122	77	120	111	128	96	75
June	112	89	69	120	138	157	125	119
July	122	100	115	106	119	141	97	156
Aug.	133	102	168	128	94	123	120	117
Sept.	102	102	109	100	124	124	105	121
Oct.	139	117	150	85	108	112	114	139
Nov.	74	140	171	136	86	107	78	74
Dec.	107	90	68	83	109	86	104	133

[1] (see page 177)

TABLE 62. JANUARY: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
7.5 - 7.9	.	.	.	.	.	.	.	1-
7.0 - 7.4	.	.	.	.	1	.	1	.-
6.5 - 6.9	.	.	.	.	1	3	9	.-
6.0 - 6.4	.	.	.	.	2	2	13	.-
5.5 - 5.9	.	.	.	1	4	11	7	1-
5.0 - 5.4	1	.	.	1	1	8	9	1-
4.5 - 4.9	.	.	.	.	4	10	5	1-
4.0 - 4.4	1	.	.	.	8	5	5	2-
3.5 - 3.9	.	1	.	.	2	9	7	3-
3.0 - 3.4	1	1	.	1	13	8	6	2-
2.5 - 2.9	1	2	.	.	5	10	6	4-
2.0 - 2.4	.	.	1	.	5	7	5	2-
1.5 - 1.9	2	.	1	.	4	11	6	6-
1.0 - 1.4	4	1	1	.	8	5	3	3-
0.5 - 0.9	5	1	.	3	8	12	10	6-
0.0 - 0.4	23	22	11	31	87	58	30	33-

TABLE 63. FEBRUARY: FREQUENCY DISTRIBUTION OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
9.0 - 9.4	.	.	.	.	.	1	2	2
8.5 - 8.9	.	.	1	.	.	3	1	.
8.0 - 8.4	.	.	.	.	1	4	3	2
7.5 - 7.9	.	.	.	.	2	6	5	2
7.0 - 7.4	.	.	.	.	.	4	6	4
6.5 - 6.9	.	.	.	.	2	6	4	1
6.0 - 6.4	.	1	1	1	3	6	4	3
5.5 - 5.9	.	1	.	1	2	7	5	1
5.0 - 5.4	.	.	.	2	3	9	5	1
4.5 - 4.9	1	.	.	.	2	4	9	3
4.0 - 4.4	1	2	.	.	3	9	8	2
3.5 - 3.9	3	1	.	1	7	7	4	6
3.0 - 3.4	.	3	.	.	3	3	1	9
2.5 - 2.9	4	.	.	.	5	10	5	1
2.0 - 2.4	3	1	1	.	1	10	4	3
1.5 - 1.9	4	2	.	1	3	6	3	3
1.0 - 1.4	3	4	.	.	6	11	6	5
0.5 - 0.9	6	1	.	.	3	8	5	1
0.0 - 0.4	30	41	14	12	75	43	18	14

TABLE 64. MARCH: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
11.0 - 11.4	.	.	.	.	.	1	.	.
10.5 - 10.9	.	.	.	.	.	2	.	.
10.0 - 10.4	.	.	.	.	1	.	3	1
9.5 - 9.9	.	1	1	.	1	6	1	1
9.0 - 9.4	.	1	3	.	4	3	1	4
8.5 - 8.9	2	3	.	1	3	2	5	3
8.0 - 8.4	1	.	1	2	1	3	3	5
7.5 - 7.9	1	2	1	.	5	1	5	3
7.0 - 7.4	1	1	.	.	2	5	5	4
6.5 - 6.9	2	1	2	1	4	9	2	1
6.0 - 6.4	1	3	1	3	6	1	4	3
5.5 - 5.9	1	1	.	.	5	7	3	2
5.0 - 5.4	4	2	2	.	6	2	3	1
4.5 - 4.9	6	2	2	.	8	4	4	3
4.0 - 4.4	2	4	.	1	5	4	4	2
3.5 - 3.9	3	1	.	1	4	2	5	2
3.0 - 3.4	3	.	1	.	2	5	4	1
2.5 - 2.9	1	2	1	.	.	8	4	5
2.0 - 2.4	2	1	1	4	6	4	6	1
1.5 - 1.9	4	1	2	.	6	3	5	2
1.0 - 1.4	1	4	1	8	8	7	4	2
0.5 - 0.9	2	1	1	4	3	8	3	4
0.0 - 0.4	28	49	26	27	53	18	16	6

TABLE 65. APRIL: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
13.0 - 13.4	1	3	.	1	.	.	.	.
12.5 - 12.9	2	1	1	.	1	.	1	1
12.0 - 12.4	.	.	.	.	1	2	1	1
11.5 - 11.9	1	2	1	.	1	1	1	1
11.0 - 11.4	1	.	2	.	1	1	4	.
10.5 - 10.9	2	4	2	.	.	3	2	.
10.0 - 10.4	2	2	.	.	1	8	3	.
9.5 - 9.9	3	1	1	.	1	1	4	1
9.0 - 9.4	1	3	1	1	2	8	3	.
8.5 - 8.9	4	2	1	.	3	6	.	1
8.0 - 8.4	1	1	1	1	3	2	2	1
7.5 - 7.9	3	1	.	1	2	7	3	4
7.0 - 7.4	4	.	.	1	2	2	5	1
6.5 - 6.9	3	1	.	1	4	4	6	5
6.0 - 6.4	.	1	.	2	2	6	3	1
5.5 - 5.9	4	2	.	2	4	8	4	2
5.0 - 5.4	4	1	1	.	2	5	6	2
4.5 - 4.9	5	.	1	1	7	5	6	2
4.0 - 4.4	2	1	.	1	4	3	3	2
3.5 - 3.9	1	.	1	1	2	8	7	1
3.0 - 3.4	4	2	1	2	2	6	6	1
2.5 - 2.9	4	5	.	2	3	6	5	2
2.0 - 2.4	8	2	2	1	5	9	5	1
1.5 - 1.9	5	1	1	1	1	4	6	2
1.0 - 1.4	8	3	1	2	2	12	3	2
0.5 - 0.9	4	3	.	.	13	5	3	2
0.0 - 0.4	34	19	13	11	10	20	6	5

TABLE 66. MAY: FREQUENCY DISTRIBUTION OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
15.0 - 15.4	.	.	1	.	.	.	1	.
14.5 - 14.9	1	3	1	1	1	.	.	.
14.0 - 14.4	.	3	1	.	1	1	.	.
13.5 - 13.9	3	.	.	.	.	.	.	.
13.0 - 13.4	4	.	1	1	1	2	.	.
12.5 - 12.9	5	2	1	.	.	.	4	.
12.0 - 12.4	2	4	2	.	6	3	1	1
11.5 - 11.9	1	3	2	2	4	4	1	1
11.0 - 11.4	.	6	2	1	1	.	.	1
10.5 - 10.9	1	5	.	.	2	4	3	1
10.0 - 10.4	6	2	1	1	4	4	4	.
9.5 - 9.9	4	3	.	1	4	6	.	.
9.0 - 9.4	5	2	.	1	2	6	2	1
8.5 - 8.9	2	4	1	1	1	3	.	4
8.0 - 8.4	6	5	1	2	1	5	3	.
7.5 - 7.9	5	3	1	2	1	5	1	2
7.0 - 7.4	4	4	.	1	1	3	.	1
6.5 - 6.9	6	3	1	1	3	2	1	1
6.0 - 6.4	6	5	1	1	7	2	4	2
5.5 - 5.9	3	3	1	2	1	2	2	.
5.0 - 5.4	6	3	2	.	5	2	5	1
4.5 - 4.9	6	3	1	1	2	3	3	.
4.0 - 4.4	3	2	1	1	2	9	3	.
3.5 - 3.9	7	5	3	1	1	5	1	2
3.0 - 3.4	4	4	.	2	4	5	1	.
2.5 - 2.9	4	4	1	.	3	5	1	.
2.0 - 2.4	4	2	.	.	3	4	2	3
1.5 - 1.9	9	3	1	2	5	3	2	.
1.0 - 1.4	5	4	4	3	2	5	1	1
0.5 - 0.9	12	4	1	2	3	2	1	1
0.0 - 0.4	43	30	4	5	10	8	5	1

TABLE 67. JUNE: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
15.5 - 15.9	.	1	.	1	.	.	.	1
15.0 - 15.4	2	3	2	1	2	1	.	.
14.5 - 14.9	.	1	2	.	1	1	.	1
14.0 - 14.4	2	1	.	1	1	3	2	.
13.5 - 13.9	.	2	.	.	1	5	3	.
13.0 - 13.4	.	3	.	2	1	4	1	.
12.5 - 12.9	4	2	1	1	.	4	4	.
12.0 - 12.4	1	6	1	1	.	3	2	2
11.5 - 11.9	2	2	1	1	2	5	2	.
11.0 - 11.4	2	5	.	.	.	2	3	.
10.5 - 10.9	3	4	1	1	3	6	1	.
10.0 - 10.4	4	4	.	.	2	3	2	.
9.5 - 9.9	3	3	1	.	2	2	5	1
9.0 - 9.4	1	4	.	1	1	4	1	1
8.5 - 8.9	.	2	1	1	4	10	1	.
8.0 - 8.4	6	1	.	.	1	5	5	2
7.5 - 7.9	4	1	1	.	1	8	5	2
7.0 - 7.4	2	2	.	.	9	4	5	.
6.5 - 6.9	1	3	.	.	8	6	7	1
6.0 - 6.4	4	3	.	.	7	6	4	2
5.5 - 5.9	3	1	.	1	2	5	3	1
5.0 - 5.4	3	1	.	.	1	8	3	.
4.5 - 4.9	4	5	1	1	3	5	2	2
4.0 - 4.4	2	2	1	.	2	8	1	1
3.5 - 3.9	.	1	.	.	2	8	1	1
3.0 - 3.4	3	3	.	1	1	6	.	3
2.5 - 2.9	2	2	.	.	.	3	1	1
2.0 - 2.4	1	5	.	.	1	7	2	2
1.5 - 1.9	1	.	1	.	3	3	4	.
1.0 - 1.4	5	6	.	.	3	9	2	1
0.5 - 0.9	4	3	.	.	4	7	1	1
0.0 - 0.4	24	12	2	4	8	14	1	11

TABLE 68. JULY: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
15.0 - 15.4	.	.	.	.	.	.	1	.
14.5 - 14.9	.	1	1	.	.	2	.	.
14.0 - 14.4	.	1	.	.	1	1	.	.
13.5 - 13.9	.	1	.	.	.	2	1	.
13.0 - 13.4	1	1	.	.	.	.	.	1
12.5 - 12.9	2	3	1	.	.	1	3	.
12.0 - 12.4	1	1	.	1	2	2	1	2
11.5 - 11.9	.	2	.	.	.	2	6	1
11.0 - 11.4	.	2	1	1	.	2	3	.
10.5 - 10.9	1	1	.	3	1	5	.	2
10.0 - 10.4	3	2	.	.	3	5	5	.
9.5 - 9.9	.	1	.	2	7	3	2	.
9.0 - 9.4	2	.	.	.	2	4	2	1
8.5 - 8.9	1	1	1	2	4	3	8	1
8.0 - 8.4	2	2	.	2	2	2	5	1
7.5 - 7.9	1	.	.	.	3	10	2	2
7.0 - 7.4	5	3	.	1	3	5	1	1
6.5 - 6.9	2	.	.	1	5	7	2	2
6.0 - 6.4	3	3	1	1	.	7	2	2
5.5 - 5.9	1	1	3	.	1	4	3	3
5.0 - 5.4	.	1	.	.	3	8	5	.
4.5 - 4.9	3	3	3	1	1	6	11	.
4.0 - 4.4	2	4	1	2	4	9	2	2
3.5 - 3.9	1	1	.	1	4	4	7	3
3.0 - 3.4	3	2	.	.	4	5	3	.
2.5 - 2.9	3	1	.	.	2	9	3	2
2.0 - 2.4	5	3	1	.	3	9	4	4
1.5 - 1.9	1	2	.	1	6	9	4	2
1.0 - 1.4	4	2	1	1	5	6	4	2
0.5 - 0.9	4	1	1	1	6	12	8	2
0.0 - 0.4	23	19	2	4	16	14	9	15

TABLE 69. AUGUST: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
13.5 - 13.9	.	1	.	.	.	1	.	.
13.0 - 13.4	.	.	.	.	.	3	3	.
12.5 - 12.9	1	1	.	1	.	1	1	.
12.0 - 12.4	.	1	1	2	4	2	1	1
11.5 - 11.9	.	.	.	.	2	3	2	1
11.0 - 11.4	.	.	.	1	1	4	5	.
10.5 - 10.9	.	3	.	1	2	3	.	.
10.0 - 10.4	.	3	1	2	3	2	1	.
9.5 - 9.9	2	1	2	1	.	5	4	1
9.0 - 9.4	2	.	.	.	3	8	1	1
8.5 - 8.9	4	1	.	1	2	5	3	.
8.0 - 8.4	4	3	2	.	1	7	6	3
7.5 - 7.9	.	2	1	.	8	5	5	.
7.0 - 7.4	3	.	.	2	3	6	2	4
6.5 - 6.9	2	4	1	1	6	5	11	1
6.0 - 6.4	.	.	.	1	3	4	3	1
5.5 - 5.9	1	1	.	1	1	7	4	3
5.0 - 5.4	.	1	.	1	3	6	5	2
4.5 - 4.9	1	2	.	1	11	7	2	1
4.0 - 4.4	1	3	1	2	6	2	5	2
3.5 - 3.9	5	2	1	2	4	11	6	4
3.0 - 3.4	2	.	.	2	8	3	9	1
2.5 - 2.9	6	2	1	.	8	10	4	3
2.0 - 2.4	4	3	1	.	3	9	3	.
1.5 - 1.9	4	1	.	1	7	5	5	1
1.0 - 1.4	5	3	1	.	7	6	6	1
0.5 - 0.9	6	.	1	1	4	6	2	5
0.0 - 0.4	40	14	8	6	9	15	10	10

TABLE 70. SEPTEMBER: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
12.5 - 12.9	.	.	.	.	.	1	.	.
12.0 - 12.4	.	.	.	.	.	1	.	.
11.5 - 11.9	.	.	.	.	1	1	.	.
11.0 - 11.4	.	.	.	1	1	2	1	1
10.5 - 10.9	.	.	.	1	1	2	2	1
10.0 - 10.4	2	.	.	1	.	1	8	1
9.5 - 9.9	.	1	.	.	4	6	5	.
9.0 - 9.4	1	.	1	.	5	4	4	1
8.5 - 8.9	1	2	.	.	3	11	4	3
8.0 - 8.4	.	4	.	.	4	4	2	3
7.5 - 7.9	3	1	.	1	4	5	5	3
7.0 - 7.4	2	1	1	.	9	13	7	2
6.5 - 6.9	.	1	.	.	2	10	4	2
6.0 - 6.4	3	3	.	.	4	6	4	3
5.5 - 5.9	1	.	1	.	1	9	1	4
5.0 - 5.4	1	3	.	2	5	5	8	3
4.5 - 4.9	2	2	.	1	9	8	3	1
4.0 - 4.4	.	2	1	2	6	7	2	3
3.5 - 3.9	1	3	1	1	13	9	3	2
3.0 - 3.4	2	.	.	1	3	8	3	4
2.5 - 2.9	2	2	.	1	6	7	6	3
2.0 - 2.4	3	.	1	1	10	7	9	2
1.5 - 1.9	3	1	.	.	12	7	2	1
1.0 - 1.4	6	1	1	2	7	13	1	6
0.5 - 0.9	6	2	1	3	9	8	4	3
0.0 - 0.4	26	16	3	5	33	18	9	8

TABLE 71. OCTOBER: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
9.5 - 9.9	.	.	.	.	1	.	2	.
9.0 - 9.4	1	.	.	.	.	1	2	.
8.5 - 8.9	2	.	.	.	2	4	6	1
8.0 - 8.4	1	.	1	1	3	9	3	3
7.5 - 7.9	2	.	1	2	5	10	3	1
7.0 - 7.4	.	.	1	.	9	3	4	1
6.5 - 6.9	.	.	.	2	3	4	1	2
6.0 - 6.4	1	.	3	.	6	13	3	2
5.5 - 5.9	1	.	1	2	3	14	4	6
5.0 - 5.4	1	3	.	2	7	5	6	1
4.5 - 4.9	2	3	2	1	9	10	4	4
4.0 - 4.4	4	1	1	1	11	4	2	2
3.5 - 3.9	1	2	.	.	14	6	8	2
3.0 - 3.4	1	1	1	3	11	6	4	6
2.5 - 2.9	2	3	2	1	12	8	4	1
2.0 - 2.4	1	3	1	3	11	11	2	3
1.5 - 1.9	2	.	.	.	14	7	7	5
1.0 - 1.4	2	3	2	1	10	7	3	2
0.5 - 0.9	2	6	9	4	13	9	2	5
0.0 - 0.4	24	30	18	11	43	36	11	9

TABLE 72. NOVEMBER: FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
8.0 - 8.4	.	.	.	.	.	.	1	.
7.5 - 7.9	.	.	.	.	1	4	4	3
7.0 - 7.4	.	.	.	.	3	2	8	1
6.5 - 6.9	.	.	.	.	2	6	3	6
6.0 - 6.4	.	1	.	.	2	7	5	2
5.5 - 5.9	1	.	.	.	5	6	7	1
5.0 - 5.4	1	.	.	1	3	9	4	4
4.5 - 4.9	.	1	.	.	1	9	2	2
4.0 - 4.4	2	1	.	1	7	9	6	2
3.5 - 3.9	1	.	.	1	6	2	14	6
3.0 - 3.4	1	1	.	.	7	6	7	9
2.5 - 2.9	.	1	1	.	9	2	8	4
2.0 - 2.4	1	.	1	1	8	7	3	3
1.5 - 1.9	2	1	1	.	10	6	5	2
1.0 - 1.4	4	1	.	1	8	11	5	5
0.5 - 0.9	2	4	.	2	11	13	5	3
0.0 - 0.4	29	23	15	25	82	40	29	29

TABLE 73. DECEMBER: FREQUENCY DISTRIBUTION OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

hours	N	NE	E	SE	S	SW	W	NW
6.5 - 6.9	.	.	.	.	.	.	1	.
6.0 - 6.4	.	.	.	.	.	1	4	1
5.5 - 5.9	.	.	.	.	2	5	10	2
5.0 - 5.4	.	.	.	.	1	6	13	1
4.5 - 4.9	.	.	.	1	5	6	8	3
4.0 - 4.4	.	.	.	.	8	11	7	1
3.5 - 3.9	.	1	.	.	3	8	3	3
3.0 - 3.4	.	.	.	1	6	13	11	3
2.5 - 2.9	1	2	.	.	9	6	9	1
2.0 - 2.4	2	.	1	.	10	6	4	1
1.5 - 1.9	4	1	.	.	12	9	3	6
1.0 - 1.4	2	1	.	1	7	9	5	6
0.5 - 0.9	2	.	1	1	13	14	6	3
0.0 - 0.4	30	17	16	38	116	61	36	33

TABLE 74. JANUARY: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	.	.	.	0.9	3.4	5.8	17.1	1.7
80 - 89	0.4	.	.	2.4	2.8	7.7	11.4	1.9
70 - 79	2.1	.	.	1.8	4.6	7.8	7.9	3.1
60 - 69	3.0	1.2	.	0.4	6.2	6.9	8.1	5.3
50 - 59	2.2	4.5	.	0.4	5.7	7.6	7.9	6.5
40 - 49	1.9	5.1	2.5	0.9	5.8	7.6	7.1	6.1
30 - 39	2.8	1.9	7.5	0.4	5.4	7.6	6.4	7.1
20 - 29	7.8	1.2	8.7	1.3	4.8	8.3	6.7	9.7
10 - 19	13.1	3.2	6.5	3.6	5.8	8.0	7.0	9.9
0 - 9	60.5	78.9	78.6	84.0	56.9	36.2	24.6	51.0

[1] see page 64

TABLE 75. FEBRUARY: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	.	.	3.9	.	1.4	6.3	8.6	8.6
80 - 89	.	0.4	1.3	1.2	2.0	6.3	8.8	7.9
70 - 79	.	1.3	2.7	5.7	3.1	6.9	8.2	5.7
60 - 69	0.4	1.4	1.3	8.8	3.3	7.2	8.8	4.2
50 - 59	2.5	1.7	.	7.2	4.1	7.1	10.5	6.4
40 - 49	5.4	3.6	.	3.9	5.9	7.9	9.7	10.8
30 - 39	7.4	4.5	1.6	2.0	5.5	8.3	7.0	12.1
20 - 29	9.5	5.9	3.3	2.4	5.0	9.4	6.8	10.9
10 - 19	10.9	8.5	2.2	3.3	6.5	10.4	8.3	11.4
0 - 9	62.5	70.0	78.5	63.8	61.4	30.5	21.5	22.1

[1] see page 64

TABLE 76. MARCH: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	0.7	1.4	1.9	0.4	1.8	4.3	4.2	4.3
80 - 89	2.0	2.9	4.1	1.7	3.5	5.1	6.1	8.8
70 - 79	3.7	3.2	5.1	3.6	4.7	7.6	8.5	12.2
60 - 69	4.5	3.5	4.2	3.9	6.1	10.6	9.0	10.9
50 - 59	7.1	4.8	4.5	3.9	8.5	9.5	8.4	8.9
40 - 49	10.9	5.3	5.1	2.6	9.3	6.8	8.8	7.5
30 - 39	9.9	4.9	3.7	3.5	7.1	7.9	10.3	7.4
20 - 29	7.4	4.7	4.3	8.5	6.8	10.2	11.1	8.2
10 - 19	7.8	5.7	6.3	13.8	9.2	10.9	11.1	8.2
0 - 9	48.9	66.1	59.5	64.8	45.1	26.6	22.1	18.2

[1] see page 64

TABLE 77. APRIL: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	2.8	8.1	8.1	2.1	2.8	2.2	3.9	4.4
80 - 89	3.2	7.1	10.0	0.7	3.0	4.7	6.3	2.7
70 - 79	4.5	8.0	8.5	2.4	5.2	7.9	6.9	2.9
60 - 69	6.0	6.0	5.5	4.8	8.3	8.3	6.9	9.0
50 - 59	6.6	4.4	2.4	8.3	9.3	8.7	9.8	14.8
40 - 49	6.3	4.2	1.4	9.9	10.6	9.6	11.5	12.7
3o - 39	6.9	5.1	2.9	9.4	11.7	9.4	12.5	9.6
20 - 29	9.3	7.3	6.1	10.3	9.8	10.9	13.9	8.8
10 - 19	12.5	8.1	9.3	10.5	8.4	12.7	13.5	8.5
0 - 9	37.8	38.5	43.6	37.5	30.3	21.8	10.7	18.8

[1] see page 64

TABLE 78. MAY: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	3.8	4.8	9.6	2.9	4.5	2.3	4.5	1.4
80 - 89	4.2	6.4	9.9	4.8	7.2	4.7	7.2	5.3
70 - 79	4.5	8.5	9.2	8.2	9.6	9.0	9.1	8.5
60 - 69	6.5	8.3	6.2	10.3	9.3	12.7	9.5	10.9
50 - 59	8.2	8.4	6.1	10.9	8.2	11.4	8.8	16.5
40 - 49	8.8	8.7	7.7	9.7	10.1	8.1	11.3	15.1
30 - 39	9.0	8.2	10.0	9.1	10.5	9.8	14.5	8.3
20 - 29	9.0	8.0	9.9	8.9	10.2	14.0	11.8	8.3
10 - 19	9.6	7.7	7.6	7.3	11.9	14.0	9.0	11.1
0 - 9	36.0	30.6	25.3	28.6	28.7	14.8	13.4	12.6

[1] see page 64

TABLE 79. JUNE: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	2.1	5.7	16.0	12.8	3.9	3.2	2.6	3.6
80 - 89	3.4	7.3	10.9	15.1	3.6	5.7	6.6	2.7
70 - 79	6.8	10.7	11.8	13.5	4.2	7.0	10.2	3.3
60 - 69	9.0	11.9	11.3	9.2	6.4	7.9	10.7	4.5
50 - 59	8.2	9.1	7.2	6.7	11.8	10.0	12.9	6.6
40 - 49	8.2	6.5	4.7	4.1	17.1	11.2	16.7	8.1
30 - 39	9.1	6.8	4.1	5.1	14.9	11.8	13.3	10.0
20 - 29	7.7	8.2	6.7	5.9	9.4	11.7	7.8	11.9
10 - 19	5.5	8.3	7.5	3.0	6.7	9.8	7.6	10.6
0 - 9	35.0	22.4	12.5	22.2	19.9	18.3	5.2	35.1

[1] see page 64

TABLE 80. JULY: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	1.1	4.5	5.9	.	0.7	1.9	1.8	0.7
80 - 89	2.3	6.5	5.9	2.0	0.8	2.4	4.4	2.5
70 - 79	3.0	7.3	4.4	9.0	4.3	4.5	7.2	4.5
60 - 69	4.7	6.1	2.9	16.0	9.1	6.4	9.1	5.0
50 - 59	7.4	4.9	2.9	15.0	10.7	8.3	9.6	6.5
40 - 49	8.9	5.8	9.4	9.5	9.6	11.3	11.1	8.4
30 - 34	8.3	8.5	15.8	8.1	8.7	12.3	15.2	8.8
20 - 29	8.9	10.0	12.3	8.9	10.9	12.9	13.9	10.9
10 - 19	10.8	9.7	5.9	6.7	12.8	15.1	10.5	14.0
0 - 9	41.9	32.9	23.7	24.0	30.6	20.1	19.6	38.0

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[1] see page 64

TABLE 81. AUGUST: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	0.6	3.1	1.5	5.3	2.1	3.9	4.7	1.5
80 - 89	0.3	5.4	3.7	8.8	4.6	4.7	4.7	2.2
70 - 79	2.1	8.9	6.2	10.4	5.5	6.5	4.1	2.2
60 - 69	5.9	7.9	9.1	7.9	6.3	9.7	6.7	5.7
50 - 59	6.2	7.7	9.5	6.9	8.6	10.7	10.6	10.5
40 - 49	3.7	9.6	6.3	9.4	11.5	9.9	12.3	11.0
30 - 39	4.1	9.2	4.7	12.5	14.7	10.2	12.5	11.4
20 - 29	9.0	8.1	6.2	11.3	15.6	12.2	12.6	11.7
10 - 19	13.2	9.3	7.8	6.9	15.5	14.4	12.1	10.3
0 - 9	51.7	30.3	42.8	22.1	16.7	16.3	16.5	32.8

[1] see page 64

TABLE 82. SEPTEMBER: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	1.3	0.9	.	6.1	2.2	4.1	7.3	2.4
80 - 89	2.8	2.7	2.5	4.6	3.5	5.5	5.5	3.5
70 - 79	4.2	6.0	7.0	2.3	6.1	8.7	11.3	7.0
60 - 69	5.3	9.3	6.3	1.8	7.2	10.3	11.8	9.8
50 - 59	5.3	10.0	4.2	3.6	6.2	10.4	10.5	10.6
40 - 49	4.2	10.1	8.7	8.9	8.1	10.4	9.9	10.6
30 - 39	4.4	9.8	10.5	12.3	10.7	10.5	9.4	10.8
20 - 29	8.1	6.7	7.7	11.4	10.9	11.0	9.9	12.1
10 - 19	12.1	4.1	9.3	10.2	12.3	11.5	10.3	12.5
0 - 9	50.6	43.7	40.3	38.4	31.0	17.0	15.2	20.7

[1] see page 64

TABLE 83. OCTOBER: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	5.8	.	1.5	2.7	2.4	5.5	10.5	3.4
80 - 89	4.3	.	2.7	5.4	3.8	6.9	7.2	4.9
70 - 79	2.3	.	4.6	6.2	5.1	8.6	6.6	7.9
60 - 69	3.1	2.0	6.0	6.3	5.3	10.7	8.4	9.7
50 - 59	6.3	5.4	5.2	7.0	6.3	9.1	9.1	8.7
40 - 49	8.3	6.1	4.3	7.1	9.4	6.8	9.5	9.7
30 - 39	6.5	6.6	4.3	8.5	11.8	7.9	10.7	11.3
20 - 29	5.7	7.7	5.1	8.3	12.2	9.3	10.2	10.1
10 - 19	7.1	7.0	5.4	5.6	12.3	9.1	10.5	10.5
0 - 9	49.2	62.2	61.5	42.1	28.0	25.3	14.8	23.2

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[1] see page 64

TABLE 84. NOVEMBER: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	.	1.3	.	.	2.5	7.2	10.2	8.0
80 - 89	.	2.1	.	0.5	2.4	7.3	7.7	5.5
70 - 79	1.8	2.2	.	1.1	1.6	8.3	5.6	4.1
60 - 69	2.3	2.9	.	1.7	2.9	8.9	6.4	4.9
50 - 59	3.7	3.5	.	2.3	5.0	7.5	9.9	9.1
40 - 49	3.9	3.5	2.0	1.7	6.9	6.2	10.0	12.4
30 - 39	3.5	3.3	5.9	1.1	7.6	5.6	7.4	8.4
20 - 29	6.5	4.8	5.9	2.1	8.2	7.3	6.3	5.2
10 - 19	9.6	7.2	2.6	4.1	8.3	10.4	6.3	6.6
0 - 9	68.2	73.7	83.2	81.1	53.3	33.4	27.1	37.3

[1] see page 64

TABLE 85. DECEMBER: ADJUSTED[1] FREQUENCY DISTRIBUTIONS OF DAILY SUNSHINE DURATION, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

percentage of possible duration	N	NE	E	SE	S	SW	W	NW
90 +	.	.	.	0.2	1.2	8.2	13.1	4.6
80 - 89	.	.	.	0.7	2.1	6.5	1o.7	3.6
70 - 79	.	1.6	.	0.7	3.2	6.5	7.3	4.0
60 - 69	.	3.2	.	1.0	3.3	8.1	6.6	5.6
50 - 59	0.8	4.5	.	1.5	4.0	8.2	9.0	5.1
40 - 49	3.1	5.7	1.7	0.7	5.6	6.2	8.7	3.0
30 - 39	6.1	4.3	3.5	0.4	6.3	5.4	5.5	4.5
20 - 29	7.6	2.8	3.5	1.5	6.8	7.7	4.7	7.9
10 - 19	7.1	1.9	4.6	2.5	7.7	9.9	5.5	8.5
0 - 9	73.1	77.2	88.8	90.0	60.1	39.0	30.0	51.7

[1] see page 64

TABLE 86. DAILY SUNSHINE DURATION: MEANS PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962 (hours)

	N	NE	E	SE	S	SW	W	NW
Jan.	0.9	0.7	0.6	0.7	1.5	2.3	3.1	1.4
Feb.	1.0	1.1	1.2	1.7	1.6	3.1	3.9	3.4
March	2.6	2.1	2.5	1.7	2.9	4.2	4.2	5.0
April	3.7	4.6	4.3	3.5	4.3	4.7	5.4	4.9
May	4.6	5.6	6.6	5.5	6.0	6.1	6.4	6.4
June	5.4	6.6	9.1	8.4	6.2	6.3	7.7	4.6
July	3.9	4.9	5.5	6.1	4.5	5.3	5.8	4.1
Aug.	2.7	4.8	4.1	5.6	4.8	5.5	5.5	4.1
Sept.	2.5	3.5	3.2	3.6	3.7	4.8	5.5	4.4
Oct.	2.5	1.4	1.9	2.8	3.0	3.7	4.4	3.5
Nov.	1.0	1.0	0.6	0.8	1.7	2.8	3.5	2.7
Dec.	0.6	0.7	0.4	0.5	1.1	1.9	2.8	1.5

TABLE 87. DAILY SUNSHINE DURATION: ANOMALIES[1] PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962 (hours)

	N	NE	E	SE	S	SW	W	NW
Jan.	-0.7	-0.9	-1.0	-1.0	-0.1	+0.7	+1.5	-0.2
Feb.	-1.4	-1.3	-1.2	-0.7	-0.8	+0.7	+1.5	+1.0
March	-0.7	-1.2	-0.8	-1.6	-0.4	+0.9	+0.9	+1.7
Apr.	-0.9	0.0	-0.3	-1.1	-0.2	+0.1	+0.8	+0.4
May	-1.0	-0.1	+1.0	-0.1	+0.4	+0.5	+0.8	+0.8
June	-0.5	+0.7	+3.2	+2.5	+0.3	+0.4	+1.8	-1.3
July	-1.1	-0.1	+0.5	+1.1	-0.5	+0.3	+0.8	-0.9
Aug.	-1.9	+0.2	-0.5	+1.0	+0.2	+0.9	+0.9	-0.5
Sept.	-1.6	-0.5	-0.9	-0.5	-0.4	+0.7	+1.4	+0.3
Oct.	-0.5	-1.6	-1.1	-0.2	0.0	+0.7	+1.4	+0.5
Nov.	-1.0	-1.0	-1.4	-1.2	-0.3	+0.8	+1.5	+0.7
Dec.	-0.8	-0.7	-1.0	-0.9	-0.3	+0.5	+1.4	+0.1

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[1] see page 54

TABLE 88. SUNLESS DAYS: FREQUENCY[1] PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962 (percentages)

	N	NE	E	SE	S	SW	W	NW
Jan.	39	64	79	81	50	28	17	42
Feb.	40	60	82	61	50	15	13	17
March	35	53	48	46	32	10	11	5
April	21	20	32	34	7	7	3	7
May	18	17	11	11	5	4	2	-
June	24	10	13	5	8	3	1	22
July	18	18	11	8	5	3	5	23
Aug.	31	19	3	13	5	4	6	17
Sept.	29	29	-	9	18	6	5	10
Oct.	38	45	36	21	17	13	9	9
Nov.	50	56	83	72	38	17	18	26
Dec.	53	68	72	81	56	32	24	41

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[1] expressed as percentages of total days per wind direction and month

TABLE 89. DAYS WITH 0 - 9%[1] OF POSSIBLE SUNSHINE DURATION: FREQUENCY[2] PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

	N	NE	E	SE	S	SW	W	NW
Jan.	61	79	79	84	57	36	25	51
Feb.	63	70	80	64	61	31	21	22
Mar.	49	66	59	65	45	27	23	18
April	38	39	44	37	30	22	11	19
May	36	31	25	29	19	15	13	13
June	35	22	13	22	20	18	5	35
July	42	33	24	24	31	20	20	38
Aug.	52	30	43	22	17	16	17	33
Sept.	51	44	40	38	31	17	15	21
Oct.	49	62	61	42	28	25	15	23
Nov.	68	74	83	81	53	33	27	37
Dec.	73	77	89	90	60	39	30	52

[1] in January and December frequencies refer to days with 0 - 7% of possible duration (see page 70)

[2] expressed as percentages of total days per wind direction and month

TABLE 90. HIGH RATES[1] OF SUNSHINE PRODUCTION: FREQUENCIES,[2] PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962
(percentages)

	N	NE	E	SE	S	SW	W	NW
Jan.	.	.	.	3.9	7.0	13.7	29.9	3.6
Feb.	.	.	5.9	.	2.8	12.4	18.0	17.2
Mar.	2.1	4.3	5.7	1.3	4.8	10.8	8.0	11.0
April	5.9	16.3	19.4	3.1	5.2	4.8	10.1	7.2
May	9.0	9.6	20.1	5.8	11.2	5.9	11.5	4.2
June	4.2	11.9	25.0	27.6	7.8	8.4	7.9	5.4
July	4.0	10.6	11.8	.	1.1	3.8	4.6	2.0
Aug.	1.0	5.6	4.5	13.0	6.4	8.8	10.7	4.4
Sept.	3.9	2.8	.	11.9	4.9	8.6	19.3	4.7
Oct.	11.5	.	4.4	8.1	5.5	13.4	19.1	8.3
Nov.	.	4.1	.	.	4.6	14.4	17.8	13.8
Dec.	.	.	.	0.8	2.5	14.4	24.8	8.3

[1] see page 120

[2] expressed as percentages of total days per wind direction and month

N.B. equivalent frequencies of days with low rates of sunshine production are contained in Table 89

TABLE 91. MEDIUM[1] RATES OF SUNSHINE PRODUCTION: FREQUENCIES[2] PER WIND DIRECTION AND MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962
(percentages)

	N	NE	E	SE	S	SW	W	NW
Jan.	27.2	17.6	24.9	7.3	25.6	39.5	35.3	39.1
Feb.	36.5	24.4	6.6	17.3	27.6	42.4	43.3	52.8
Mar.	43.0	26.4	23.6	34.3	42.5	43.7	49.6	40.0
April	42.8	28.1	20.6	49.3	49.9	51.3	63.7	58.7
May	44.3	41.5	42.3	46.6	49.1	55.8	54.2	64.4
June	37.6	37.0	28.9	25.7	59.7	55.3	58.2	48.2
July	45.1	38.5	49.3	46.1	51.9	60.0	59.2	49.7
Aug.	36.3	45.7	35.6	45.8	67.6	57.7	61.7	59.0
Sept.	34.4	40.2	39.7	45.4	47.5	53.9	49.2	56.0
Oct.	34.3	34.5	22.4	36.3	52.4	39.4	51.0	48.9
Nov.	29.0	22.0	15.8	12.8	37.2	36.5	36.6	42.8
Dec.	24.4	17.0	13.8	7.5	30.5	38.4	35.5	27.5

[1] see page 120

[2] expressed as percentages of total days per wind direction and month

NB equivalent frequencies of days with low rates of sunshine production are contained in Table 89

TABLE 92. JULY: RELATIONSHIPS BETWEEN DAILY SUNSHINE DURATION AND MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

Wind Direction	Number of Days	Correlation Coefficient	Regression[1]
N	76	+0.66	t= 1.1s + 60.9
NE	64	+0.74	t= s + 61.2
E	17	+0.59	t= 0.7s + 62.2
SE	24	+0.76	t= 0.8s + 63.3
S	87	+0.51	t= 0.6s + 65.2
SW	159	+0.26	t= 0.4s + 65.4
W	109	+0.60	t= 0.7s + 62.8
NW	50	+0.71	t= 1.1s + 61.6

[1] t = °F, s = hours

TABLE 93. JANUARY: RELATIONSHIPS BETWEEN DAILY SUNSHINE DURATION AND MAXIMUM TEMPERATURE, PER WIND DIRECTION, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

Wind Direction	Number of Days	Correlation Coefficient	Regression[1]
S	157	+0.09	/
SW	162	-0.50	t= -1.1s + 48.5
W	126	-0.38	t= - s + 45.9
NW	64	+0.17	/

[1] t= °F, s= hours

TABLE 94. NE WINDS: RELATIONSHIPS BETWEEN DAILY SUNSHINE DURATION AND MAXIMUM TEMPERATURE, PER MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

Month	Number of Days	Coefficient of correlation	Regression[1]
Jan.	31	/	/
Feb.	66	/	/
Mar.	81	+0.54	$t = s + 41.0$
Apr.	60	+0.44	$t = 0.7s + 47.0$
May	119	+0.51	$t = 0.8s + 52.6$
June	94	+0.62	$t = s + 56.8$
July	64	+0.74	$t = s + 61.2$
Aug.	51	+0.71	$t = 1.7s + 59.8$
Sept.	45	+0.56	$t = 0.9s + 58.2$
Oct.	56	+0.17	/
Nov.	36	/	/
Dec.	21	/	/

[1] $t = {}^{o}F$, s = hours

TABLE 95. SW WINDS: RELATIONSHIPS BETWEEN DAILY SUNSHINE DURATION AND MAXIMUM TEMPERATURE, PER MONTH, DURHAM OBSERVATORY, JULY 1937 TO JUNE 1962

Month	Number of Days	Correlation Coefficient	Regression[1]
Jan.	162	-0.50	$t = -1.1s + 48.5$
Feb.	151	-0.08	/
Mar.	107	+0.32	$t = 0.5s + 49.5$
Apr.	141	+0.25	$t = 0.6s + 53.4$
May	98	+0.21	$t = 0.3s + 59.3$
June	162	+0.33	$t = 0.4s + 62.5$
July	159	+0.26	$t = 0.4s + 65.4$
Aug.	160	+0.32	$t = 0.4s + 64.8$
Sept.	170	+0.22	$t = 0.5s + 61.2$
Oct.	167	+0.10	/
Nov.	137	-0.03	/
Dec.	162	-0.11	/

[1] $t = {}^{o}F$, s = hours

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The references contained in this bibliography are drawn from two main groups of sources. The journals include the Quarterly Journal of the Royal Meteorological Society (Quart. J.R. met. Soc.), the Meteorological Magazine (Met. Mag.), Weather and the Marine Observer. The occasional publications of the Meteorological Office include the Professional Notes, the Geophysical Memoirs and the Scientific Papers.

The bibliography is in two parts. The first part lists alphabetically the references contained in the text. The second part lists alphabetically additional references which were consulted during the preparation of this thesis.

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