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RETIREMENT OF MR R. F. JONES AND DR F. PASQUILL

On 7 September 1974 the Meteorological Office lost the services of two of its senior scientists. Both Mr R. F. Jones and Dr F. Pasquill retired on that day after many years' service in the Office.

Mr R. F. Jones

Mr R. F. Jones joined the Meteorological Office as a Technical Officer in 1938, having graduated from the University of Oxford in both Mathematics and Physics. In common with most recruits at that time of pre-war expansion, he soon found himself engaged on forecasting duties first at the airfields of South Cerney and Aldergrove and later, during the war, at Headquarters Coastal Command and as officer-in-charge of the Meteorological Office at Nassau in the Bahamas.

The end of the Second World War found Mr R. F. Jones at the Central Forecasting Office at Dunstable, but his career in meteorological research began shortly afterwards and he was to continue in research posts until his retirement. In 1946 the Meteorological Office acquired a Royal Air Force radar station for the purpose of exploiting radar to study clouds and precipitation. Mr R. F. Jones was placed in charge of the investigations, and over the following seven years he made important contributions to radar meteorology using the obsolescent war-time radars at East Hill, a few miles from Dunstable. The importance of this work was recognized by the award to him of the L. G. Groves Memorial Prize for Meteorology in 1953.

In 1953 Mr Jones moved to the Meteorological Office Headquarters in Kingsway, London, to join the branch concerned with research in atmospheric physics. At that time there was relatively little laboratory work in atmospheric physics conducted in the Office, but Mr Jones made important contributions to the application of meteorological knowledge to practical aviation problems. He took an active part in the inquiries into the problems of flame-out on the Britannia aircraft, and into the disaster at Munich when an aircraft crashed during take-off in snow and slush. Mr Jones served on several working groups of the World Meteorological Organization and contributed two important *Technical Notes*—on meteorological radar and ice formation on aircraft which were published by the Organization.

Mr Jones was promoted to Senior Principal Scientific Officer in 1960 to head the Atmospheric Physics Branch and subsequently spent four years as Assistant Director in charge of Special Investigations. In 1971 he was promoted to Deputy Chief Scientific Officer and took charge of all Physical Research within the Research Directorate. One of his main responsibilities during this period was the organizing of the United Kingdom contribution to the GARP Atlantic Tropical Experiment—a major international expedition in which four British ships took part as well as the Hercules aircraft of the Meteorological Research Flight. During this period he also undertook the quite onerous duties of the Treasurer of the Royal Meteorological Society.

With Mr Jones's retirement the Meteorological Office will miss his broad experience and wise technical judgement.

Dr F. Pasquill

Dr Pasquill joined the Meteorological Office in 1937 having graduated at Durham with First Class Honours and done some post-graduate work. He soon found himself a member of the small meteorological research team which was maintained at Porton for studies of atmospheric diffusion in support of the work of the Chemical Defence Research Establishment. Frank Pasquill remained a member of this research group until 1946 during which period he spent some time in Australia studying diffusion under semi-tropical conditions.

In the post-war reorganization of the Meteorological Office it was decided that the application of meteorology to agriculture should be developed and a small research group was established at Cambridge with Dr Pasquill in charge. At Cambridge he made important advances in the application of turbulence theory to the measurement of evaporation from crops and in 1950 he was granted the degree of Doctor of Science by Durham University in recognition of his researches and also received the L. G. Groves Memorial Prize for Meteorology.

For four years in the early 1950s Frank Pasquill was at the Atomic Energy Research Establishment advising on the diffusion of material in the atmosphere at a time when the dangers of the release of radioactivity into the atmosphere were being faced seriously for the first time. However, 1954 saw him back at Porton and in charge of the meteorological research there after being granted Special Merit promotion to Senior Principal Scientific Officer in recognition of his major contributions to the theory of atmospheric diffusion and its applications. In 1961 Dr Pasquill moved to the Meteorological Office at Bracknell, taking responsibility for all research in the Office on the atmospheric boundary layer and under his guidance the facilities for such studies were developed at Cardington to provide a unique capability of investigating the whole of the planetary boundary layer from a tethered balloon cable. Further Special Merit promotion to Deputy Chief Scientific Officer followed in 1966 in recognition of his continued outstanding contributions to the understanding of atmospheric turbulence.

Dr Pasquill has played an important role in many scientific activities outside the Meteorological Office and is known internationally as one of the world's leading authorities on atmospheric turbulence. In 1962 he published a book on atmospheric diffusion which is a standard work on the subject. He was editor of the *Quarterly Journal* from 1961 to 1964 and President of the Royal Meteorological Society from 1970 to 1972. He has also contributed considerably to the solution of many practical problems arising in regard to atmospheric pollution, being consulted by many individuals and organizations both national and international on the diffusion of pollutants.

The Meteorological Office will seriously miss the services of Mr R. F. Jones and Dr F. Pasquill who have both played an important part in moulding its research activities over many years. Their many friends and colleagues in the Meteorological Office and in the wider scientific community at home and abroad will, I am sure, wish them both a long and happy future.

J. S. SAWYER

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AN ASSESSMENT OF TOPOGRAPHICAL CONTROLS ON THE DISTRIBUTION OF RAINFALL IN THE CENTRAL PENNINES

By GOH KIM CHUAN and J. G. LOCKWOOD
University of Leeds

Summary. This study attempts to assess the role of relief on both annual and seasonal rainfall distributions in the central Pennines. Instead of using the common relief parameters such as spot altitude, exposure, aspect, etc., mean relief is introduced. Very high correlations are obtained for the east Pennine region when mean altitude at 8-km radius is applied. The relationship in west Pennines is not so good though statistically significant. It is suggested that mean altitude at 8-km radius is the best parameter for such analysis, especially in east Pennines. The study also indicates that the wind structure is more complex over the west Pennine region than over the east.

Introduction. The effects of topography on annual and seasonal rainfall distribution have long been recognized.[1] The lifting effect *per se* and/or the triggering effect of mountain slopes on rain-bearing winds cause substantially higher amounts of precipitation on higher slopes than in the lowlands. This does not necessarily mean that precipitation will progressively and indefinitely increase upslope on a mountain range. This appears to be so in the British Isles, but work in the humid tropics has shown that the greatest precipitation occurs on the mountain slopes and does not coincide with the highest altitudes (Braak;[2] de Boer;[3] Dale[4]).

Several objective attempts had been conducted to assess statistically the influence of altitude and other topographic parameters on the distribution of annual precipitation. One of the earliest studies was conducted in western Colorado by Spreen[5] who applied graphical correlation techniques to determine the controlling influence of spot altitude, rise, orientation and exposure on mean seasonal precipitation. This was followed by Burns[6] in California. He correlated annual precipitation with topographic variables of altitude, slope, rise, aspect, and zone of influence using the same technique as Spreen. These studies suggest that altitude is an important parameter in rainfall distribution. However, not all studies in the United States have provided similar results.

Schermerhorn[7] discovered that for western Oregon and Washington, station altitude alone does not explain much of the variation in the distribution of annual precipitation.

In the United Kingdom, assessments of the annual precipitation variation with altitude have been carried out by Rodda,[8] Unwin[9] and Bleasdale and Chan.[10] Except for Unwin who used trend surface analyses, these made use of either simple linear regression or multiple correlation techniques. In these studies station spot altitude was the main topographic variable used and it was found to be the main determining factor in the distribution of annual precipitation. Other factors such as slope and exposure were the secondary variables used.

This study concerns a zone of northern England from Liverpool to north of Morecambe and extending from the coast of Lancashire on the west to the coast of Yorkshire in the east thus encompassing both sides of the Pennines (Figure 1). Similar techniques to those used by earlier workers were applied.

Relationships between annual precipitation and altitude were determined for two regions—west and east Pennines with the mountains as the divide. As the predominant rain-bearing winds come from the west or south-west this relationship may vary between one zone which is basically windward and the other which is in the 'rain-shadow'.

In earlier studies station spot altitudes were correlated against annual precipitation. Although this parameter was observed to be statistically significant, the regression coefficients obtained were not convincingly high, for in most cases it accounted for only some 50–60 per cent of the variance. It was because of this relatively low value that secondary topographic parameters were used so as to increase the correlation values and hence the percentage of explained variance, but there must be some doubt about the validity of using secondary factors, which themselves are highly correlated, as so-called independent variables. This is especially true of the regions under consideration. This study attempts to dispense with the secondary variables by using mean altitude as the sole factor.

Most of the studies in the United Kingdom cited made use of long-term precipitation values, i.e. annual totals. As a considerable amount of summer precipitation can be attributed to localized convectional thunderstorms, the use of annual precipitation alone introduces some bias into the analysis. Shaw[11] shows that at some rainfall stations—which are located in the region under study—e.g. Rotherham and Nelson, more than 90 per cent of summer rainfall comes under the category of 'thunderstorm'. Also Duckstein *et alii*[12] in their study of rainfall in the Santa Catalina Mountains near Tucson, Arizona stated 'when annual precipitation is separated into that resulting from winter frontal systems and summertime air mass convective storms, it is noted that winter precipitation is increased more than four-fold at the 2100 metres (7000 feet) as compared to that found at 1200 metres (4000 feet). For these same elevations, summer rainfall is not quite doubled'. Thus an attempt was made to look at the precipitation–elevation relationships over short-term time periods of season, month and day.

Although all the above intended analyses would be helpful in the understanding of the role of elevation on precipitation, they are not ends in themselves. They are intended to provide a start for the analysis of individual storms which are the soundest basis for determining topographic effects on

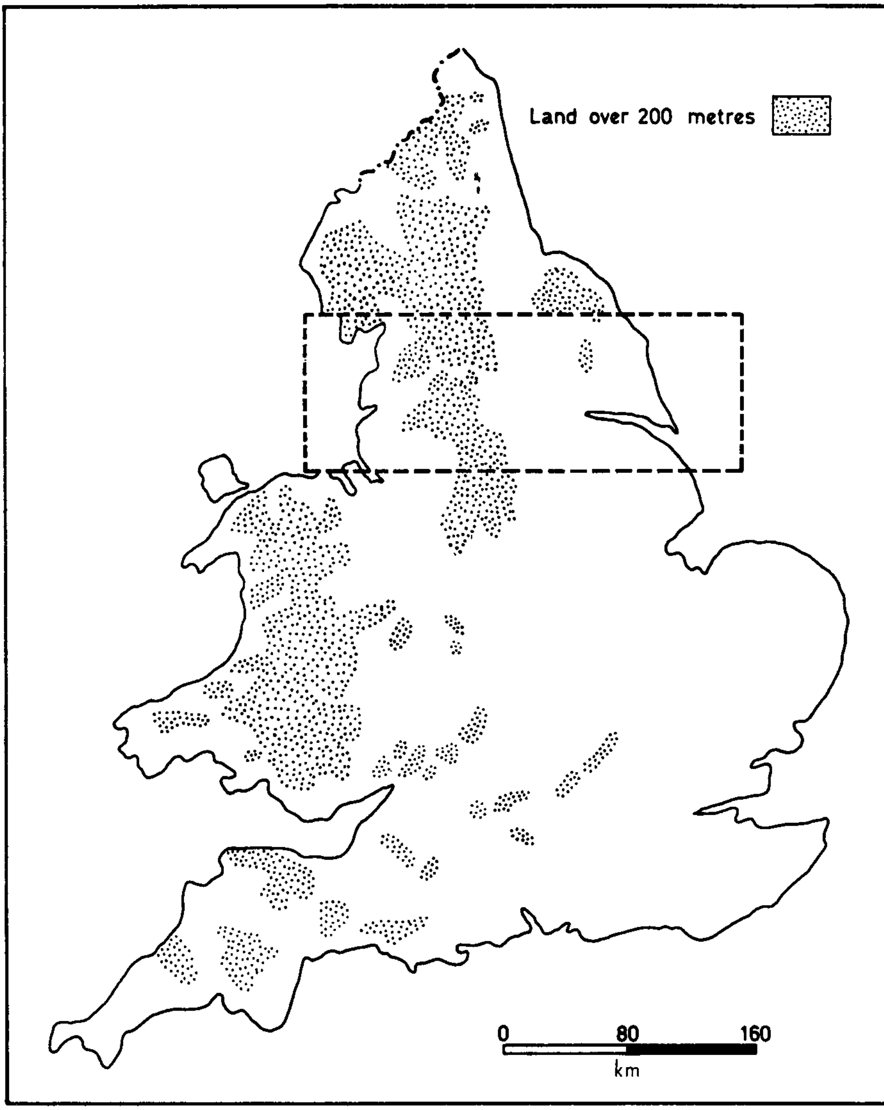


FIGURE 1—AREA OF STUDY, CENTRAL PENNINES
The area is denoted by a pecked rectangle.

precipitation. It is hoped that from such studies some models of storm precipitation on both sides of the Pennines can be produced. However, this last aim is not within the scope and content of this paper.

Analysis. Altogether about 200 rainfall stations were used in this analysis—138 stations in the east Pennines and 65 in the west Pennines. Their distribution according to altitude is given in Table I. As a first step simple linear regression was carried out between station spot altitudes and their mean annual precipitation (1916–50) as obtained from the *British Rainfall Supplement* 1961–1965[13] for

TABLE I—NUMBER OF RAINFALL STATIONS ACCORDING TO MEAN ALTITUDE AT 8-km RADIUS IN EAST AND WEST PENNINES

Mean altitude (8-km radius) *metres*	West Pennines	East Pennines
0–100	31	71
100–200	12	26
200–300	13	23
300–400	6	14
400–600	3	4
Total stations	65	138

both the east and west Pennine regions. Next, similar analyses were carried out between mean annual precipitation and station mean altitudes starting from 1 kilometre radius and extending outwards in the four cardinal directions of the compass. Topographical maps of the area to the scale 1:63 360 were used to obtain these values. The purpose of doing this was to determine the highest correlations between secondary variables of exposure and maximum rise with mean annual precipitation. As such an exercise would be too tedious to be carried out for 200 stations, a test was made for a smaller area involving 35 stations, the results of which are shown in Table II. While other parameters were also tested—slope, rise and aspect—exposure and maximum relief range were considered to be the most meaningful. Distance from the divide of the Pennines was also used as another secondary factor in preference to distance from the west coast. Multiple correlations were then carried out between mean annual precipitation and:

(a) spot altitude as the main variable and distance from the divide, exposure and maximum rise as secondary variables and

(b) mean altitude as the main variable and the others as secondary variables.

Analysis of mean monthly values (1961–66), mean seasonal precipitation (1961–66) and mean daily precipitation (1963–72) for east Pennines alone were later carried out.

Results

Mean annual precipitation. Table III shows regression coefficients between mean annual precipitation and station spot altitudes as well as mean altitudes over varying radii for west and east Pennine regions. It is evident that the use of mean altitudes gives substantially higher correlation values than spot altitudes in both the regions. However, an important feature indicated by the results is the significantly higher values obtained in the east Pennine region than in the west. Another feature that emerges for the east Pennine region is that the correlation coefficients progressively increase with increasing radius from rainfall stations until the highest value of 0·95 is attained at 8-km radius after which the coefficients start to decline. In the west Pennine region such a trend is not so obvious. Up to the 20-km radius, it is difficult to identify the radius at which the coefficient is the highest. The range between the highest and lowest correlation coefficients is 0·05 which is negligible indeed.

Tables IV and V show the results of multiple linear correlation analysis for both the east and the west Pennines using spot altitude and mean altitude (8-km radius) respectively. It is evident that for the east Pennines the inclusion of

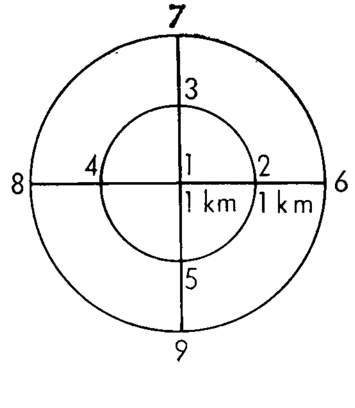
TABLE II—CORRELATION COEFFICIENTS BETWEEN MEAN ANNUAL RAINFALL (1916–50) AND EXPOSURE AND MAXIMUM RISE IN EAST PENNINES (35 STATIONS)

Radius *km*	Exposure	Maximum rise
1	−0·333	0·476
2	−0·348	0·466
3	**−0·416**	0·497
4	−0·350	0·580
5	−0·381	**0·692**
6	−0·370	0·643
7	−0·341	0·544

Exposure—the angle expressed in radians in which there is no topographical feature of height in excess of or equal to that of the gauge.
Maximum rise—the range of height between the highest and lowest points within radius specified.

TABLE III—CORRELATION COEFFICIENTS BETWEEN MEAN ANNUAL RAINFALL (1916–50) AND MEAN AND SPOT ALTITUDES FOR WEST AND EAST PENNINES

Radius *km*	West Pennines Correlation coefficient	East Pennines Correlation coefficient
1	0·6775	0·8807
2	0·7184	0·8884
3	0·7379	0·8952
4	0·7437	0·8980
5	0·7421	0·9012
6	0·7362	0·9204
7	0·7334	0·9384
8	0·7305	**0·9539**
9	0·7272	0·9420
10	0·7281	0·9023
11	0·7354	0·8642
12	0·7418	0·8557
13	0·7402	
14	0·7368	
15	0·7350	
16	0·7340	
17	0·7335	
18	0·7305	
19	0·7321	
20	0·7318	
Spot altitude	0·5957	0·8437



Mean altitude—obtained by averaging the spot altitudes of four cardinal points of compass and that of the station itself at varying radii. At 1-km radius, the sum of spot altitudes at points 1 to 5 is divided by 5 and at 2-km radius the sum of spot altitudes at points 1 to 9 is divided by 9. This is done for all the radii specified.

Spot altitude—the height in metres above sea level of the rain-gauge.

TABLE IV—MULTIPLE CORRELATION COEFFICIENT VARIANTS AND MATRIX OF SIMPLE CORRELATION COEFFICIENTS BETWEEN MEAN ANNUAL RAINFALL (1916–50) AND (a) SPOT ALTITUDE AND SECONDARY VARIABLES AND (b) MEAN ALTITUDE (8-km RADIUS) AND SECONDARY VARIABLES FOR EAST PENNINES (138 STATIONS)

(a)	Mean annual rainfall	Spot altitude	Distance from Pennines	Exposure	Maximum rise
Mean annual rainfall	1·0000	0·8437	−0·6365	−0·4462	0·8549
Spot altitude		1·0000	−0·6828	−0·3831	0·8371
Distance from Pennines			1·0000	0·5211	−0·6617
Exposure				1·0000	−0·5330
Maximum rise					1·0000

$r = 0{\cdot}8843$
$r^2 = 0{\cdot}78$

(b)	Mean annual rainfall	Mean altitude	Distance from Pennines	Exposure	Maximum rise
Mean annual rainfall	1·0000	0·9539	−0·6365	−0·4462	0·8549
Mean altitude		1·0000	−0·7125	−0·5299	0·9284
Distance from Pennines			1·0000	0·5211	−0·6617
Exposure				1·0000	−0·5330
Maximum rise					1·0000

$r = 0{\cdot}9605$
$r^2 = 0{\cdot}92$

TABLE V—MULTIPLE CORRELATION COEFFICIENT VARIANTS AND MATRIX OF SIMPLE CORRELATION COEFFICIENTS BETWEEN MEAN ANNUAL RAINFALL (1916–50) AND (a) SPOT ALTITUDE AND SECONDARY VARIABLES AND (b) MEAN ALTITUDE (8-km RADIUS) AND SECONDARY VARIABLES FOR WEST PENNINES (65 STATIONS)

(a)	Mean annual rainfall	Spot altitude	Distance from Pennines	Exposure	Maximum rise
Mean annual rainfall	1·0000	0·5957	−0·3458	−0·4774	0·3665
Spot altitude		1·0000	−0·6321	−0·2316	0·2191
Distance from Pennines			1·0000	0·5214	−0·2603
Exposure				1·0000	−0·2976
Maximum rise					1·0000

$r = 0{\cdot}7514$
$r^2 = 0{\cdot}56$

(b)	Mean annual rainfall	Mean altitude	Distance from Pennines	Exposure	Maximum rise
Mean annual rainfall	1·0000	0·7260	−0·3458	−0·4774	0·3665
Mean altitude		1·0000	−0·7167	−0·4796	0·3306
Distance from Pennines			1·0000	0·5214	−0·2603
Exposure				1·0000	−0·2976
Maximum rise					1·0000

$r = 0{\cdot}8086$
$r^2 = 0{\cdot}65$

Note: r denotes multiple correlation coefficient.

secondary factors to spot altitude does not produce substantially higher coefficients than those obtained by simple regression with the mean altitude alone. The results indicate that the use of mean altitude—in this case 8-km radius—takes into account the combined effects of spot altitude and all secondary variables that may exert influence on the rainfall distribution.

In the west Pennines very similar results were also obtained although the correlation coefficients are generally lower than those obtained in the east Pennine region. The inclusion of secondary variables with spot altitude gives a multiple correlation coefficient of 0·75 which is comparable to 0·73 obtained from the use of mean altitude alone. However, the use of mean altitude together with the secondary variables gives slightly better results of 0·80.

Using the mean altitude at 8-km radius for east Pennines the following regression equation was obtained:

$$y = 2{\cdot}023x + 564{\cdot}27 \qquad \ldots (1)$$

where

y = the predicted annual precipitation in millimetres,
x = the mean altitude at 8-km radius in metres.

It is interesting to note that at a sea-level station the predicted rainfall value, 564·27 mm, is very close to the actual mean observed values at stations such as Manby (spot altitude 15 m, mean annual rainfall 579·1 mm) and Thorne (spot altitude 5 m and mean annual rainfall 578·0 mm). The use of spot altitude produces an overestimation of precipitation at lowland stations.

For the west Pennine region the corresponding regression equation is:

$$y = 1{\cdot}890x + 916{\cdot}29. \qquad \ldots (2)$$

In contrast to the east Pennine equation this equation gives larger values for sea-level stations than those actually experienced at stations near the coast. Figure 2 shows the extent of scatter of stations along the regression lines for both regions. The excess of predicted rainfall over observed rainfall at sea-level stations on the west coast is evident from Figure 2 (top diagram). Figures 3 and 4 show the predicted rainfall map for both east and west Pennine regions based on equations (1) and (2) respectively. A comparison of Figures 3 and 4 with Figure 5 shows the close relationship between the isohyets and the mean relief pattern, especially in the east Pennines. The distribution of the anomalies or residuals in the east Pennines is shown in Figure 6. A separate analysis was also carried out for west Yorkshire involving 100 stations and the rainfall map (Figure 7) was plotted from the following equation:

$$y = 2{\cdot}356x + 534{\cdot}40 \qquad \ldots (3)$$

where y and x have the same meanings as in equation (1) above.

Seasonal precipitation. This aspect of the analysis was confined to the east Pennine region. Table VI shows the correlation coefficients between mean elevation (8-km radius) and mean monthly rainfall (1961–66). Consistently high correlations are obtained for all months especially during the winter months of November–April. The results indicate that even in the summer months the significant rainfalls experienced in this region are well distributed over large areas, i.e. about 100 km in diameter.

Table VII shows the mean seasonal correlation coefficients based on the 2–4–2–4 seasonal divisions, and the mean 24-hour seasonal rainfall (1963–72). As before, consistently high correlations between rainfall and mean elevation are obtained.

Conclusions. Spot altitude is normally used in this type of analysis. In most cases—depending on the location of the areas studied and their configura-

TABLE VI—CORRELATION COEFFICIENTS BETWEEN MEAN MONTHLY RAINFALL (1961–66) AND MEAN ALTITUDE AT 8-km RADIUS FOR EAST PENNINES

Month	Correlation coefficient
Jan.	0·9534
Feb.	0·9607
Mar.	0·9264
Apr.	0·9590
May	0·8951
June	0·8137
July	0·8441
Aug.	0·8358
Sept.	0·8372
Oct.	0·9034
Nov.	0·9424
Dec.	0·9133

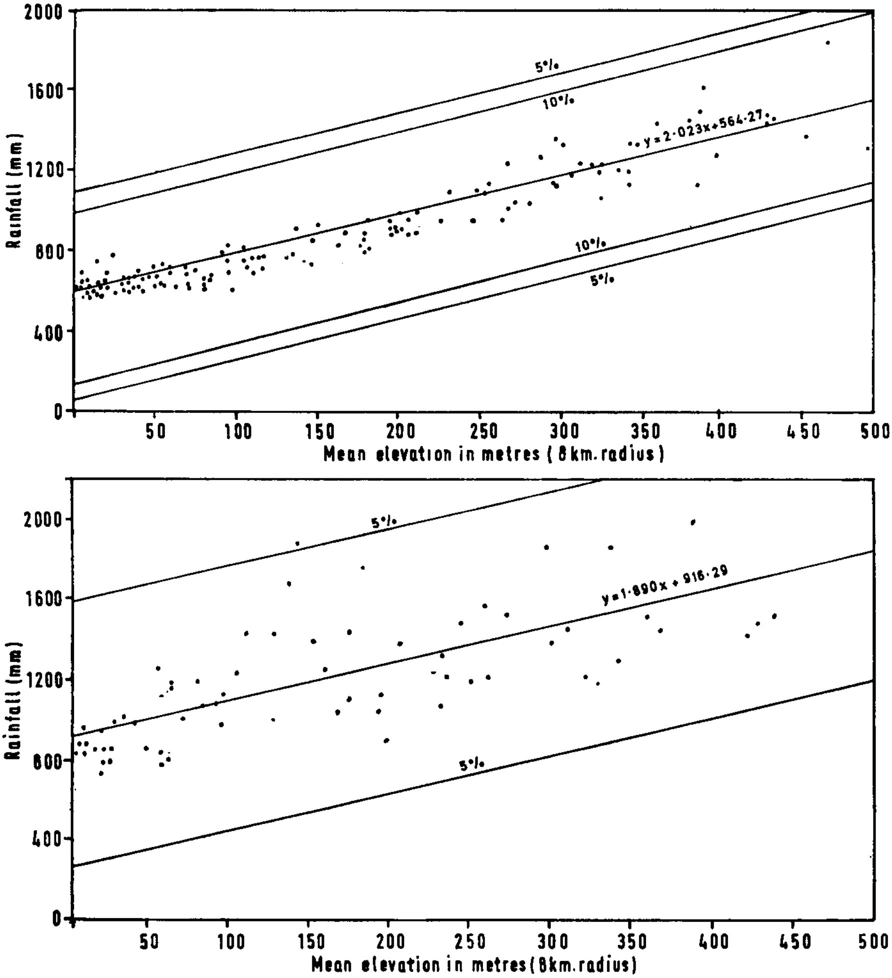


FIGURE 2—MEAN ANNUAL RAINFALL (1916–50) AND REGRESSION LINES
East Pennines in top diagram, west Pennines in bottom diagram.

TABLE VII—CORRELATION COEFFICIENTS BETWEEN (a) MEAN SEASONAL RAINFALL (1961–66) AND (b) MEAN 24-HOUR SEASONAL RAINFALL (1963–72) AND MEAN ALTITUDE AT 8-km RADIUS IN EAST PENNINES

Season	Correlation coefficient (a)	Correlation coefficient (b)
Nov.–Feb.	0·9493	0·9121
Mar.–Apr.	0·9303	0·8937
May–Aug.	0·8707	0·8183
Sept.–Oct.	0·8811	0·7599

Note: Mean 24-h seasonal rainfall is mean monthly rainfall divided by the number of rain days.

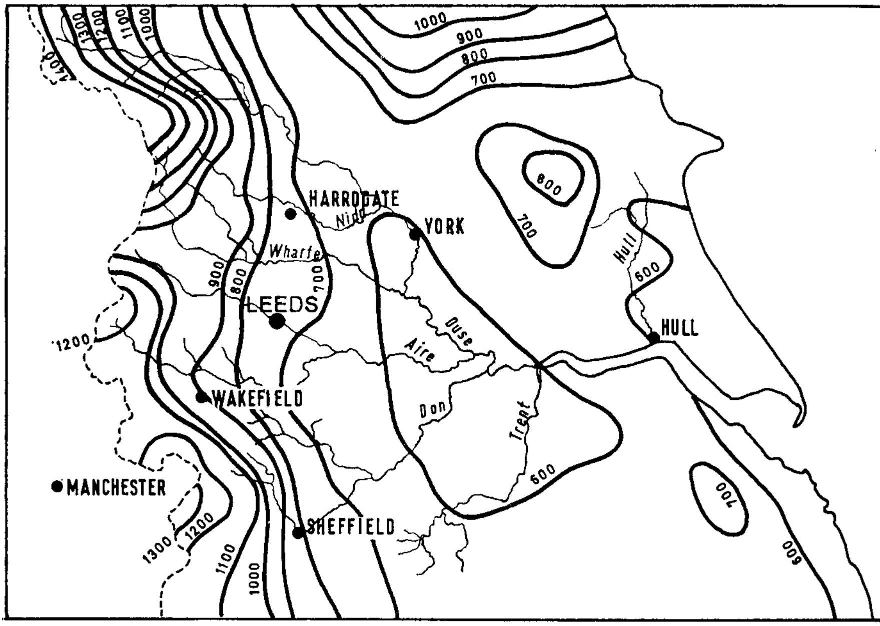


FIGURE 3—MEAN ANNUAL RAINFALL (1916–50) OF EAST PENNINES DERIVED FROM EQUATION (1)
Rainfall values are in millimetres.

tion—it accounts for some 50–60 per cent of the variation in the distribution of annual precipitation. The use of secondary variables in such studies helped to improve the correlation coefficients. This study has shown that the mean altitude over an 8-km radius around rainfall stations is more useful and the resultant equation obtained is simple and gives a very close estimate of actual mean annual values. This is especially true for the east Pennines. It is difficult to separate the influence of secondary variables on rainfall distribution and the problem which is frequently overlooked is the high correlation existing between topographic variables which have been regarded as independent variables.

The poor correlation between relief and rainfall distribution in the west Pennine region is difficult to explain. From Figure 2 it is noticeable that high rainfall amounts are recorded at 100–150 m after which there is a decrease and then a subsequent increase. The high proportion of variance not accounted for by topography may be caused by the prevailing south-westerly airstream

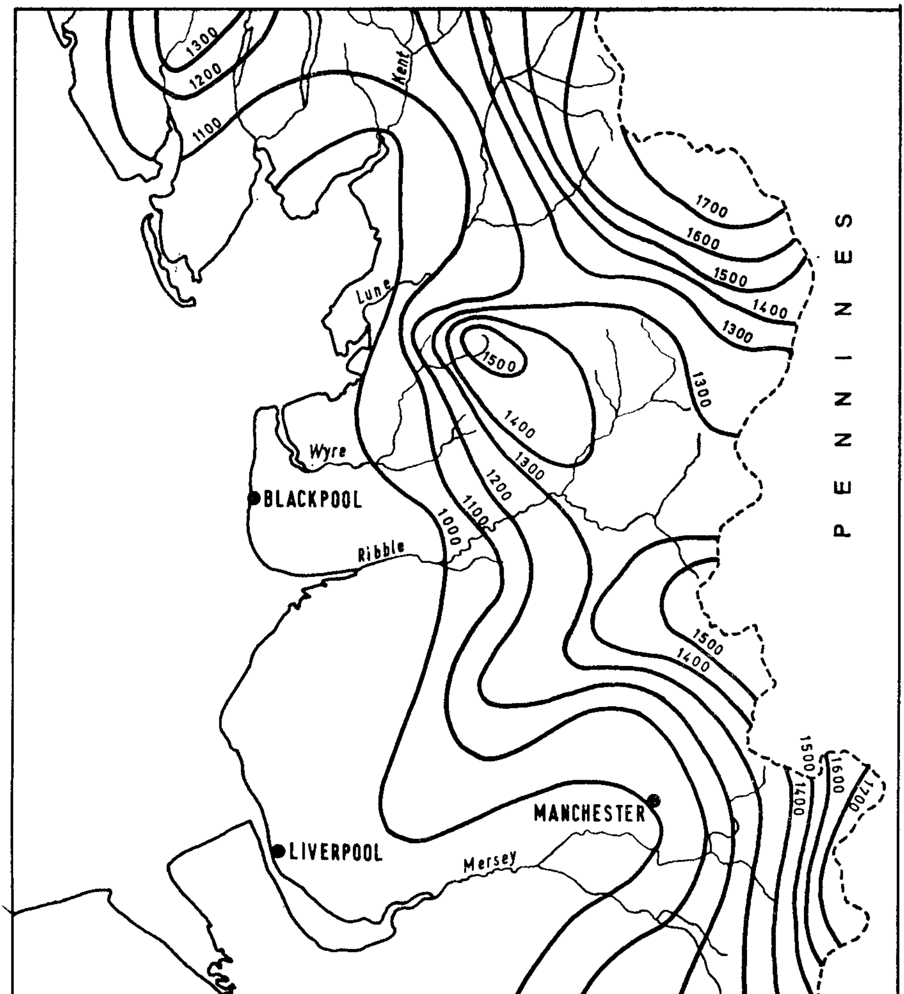


FIGURE 4—MEAN ANNUAL RAINFALL (1916–50) OF WEST PENNINES DERIVED FROM EQUATION (2)
Rainfall values are in millimetres.

starting to ascend some distance upstream of the Pennines and by the complexity of the airflow over the windward slopes.

Seasonal and monthly precipitation analyses in the east Pennines provide as high correlations as the annual precipitation analysis. This indicates that the rainfall in this region is rather widespread and that the relationship between rainfall and relief in summer months is not much affected by convectional thunderstorms.

The good results from the east Pennines indicate that a study of rainfall–relief relationships in individual storms may be worth while in this particular region.

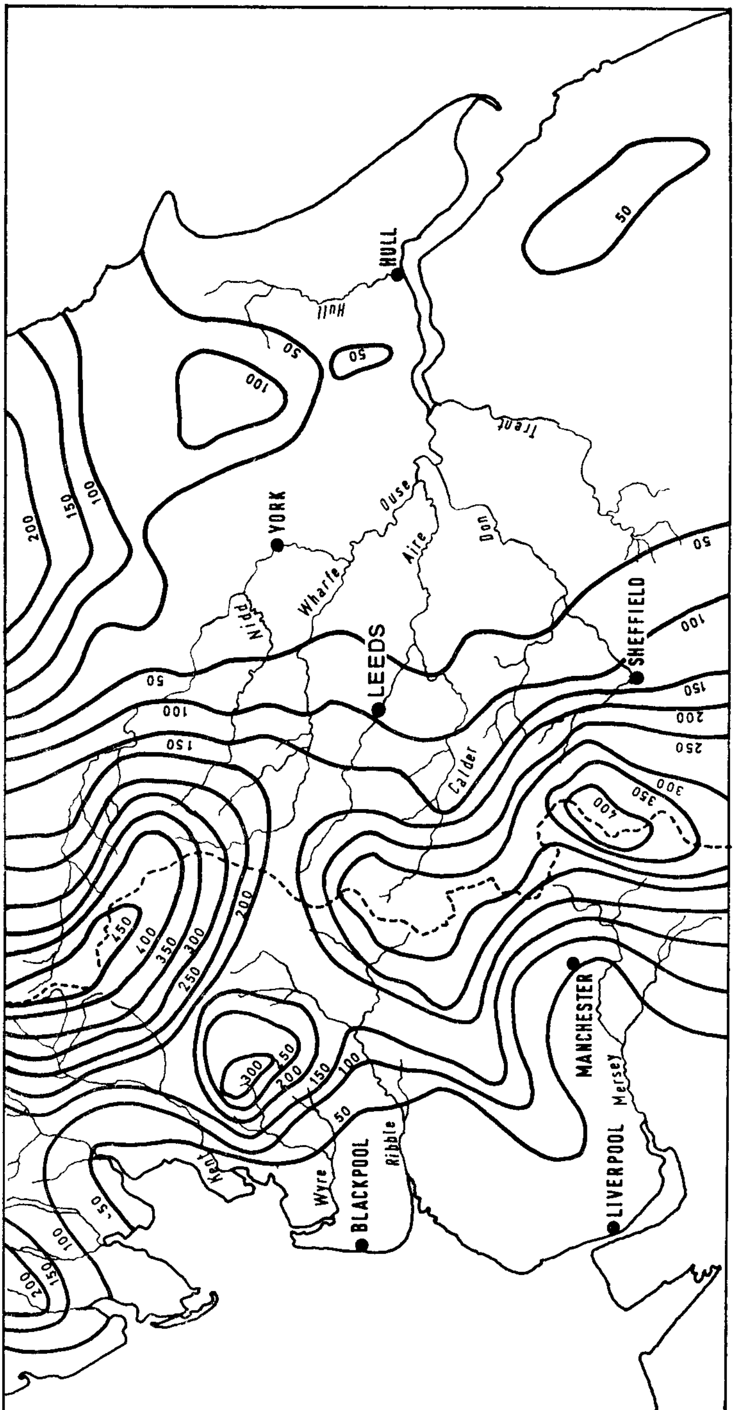


FIGURE 5—MEAN RELIEF MAP (8-km RADIUS) OF PENNINES
Heights are in metres.

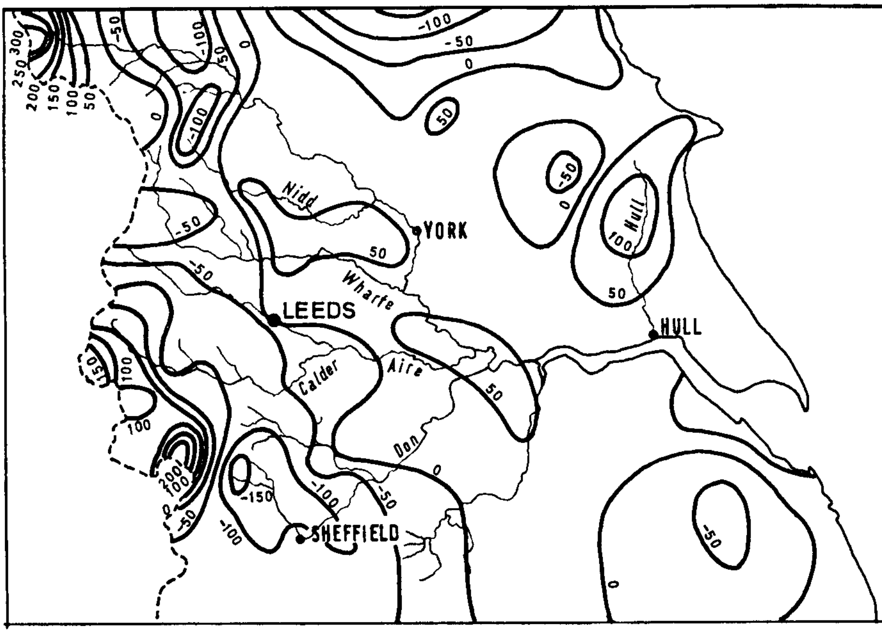


FIGURE 6—DISTRIBUTION OF RESIDUALS BETWEEN OBSERVED AND PREDICTED MEAN ANNUAL RAINFALL (1916–50) OF EAST PENNINES
Rainfall values are in millimetres.

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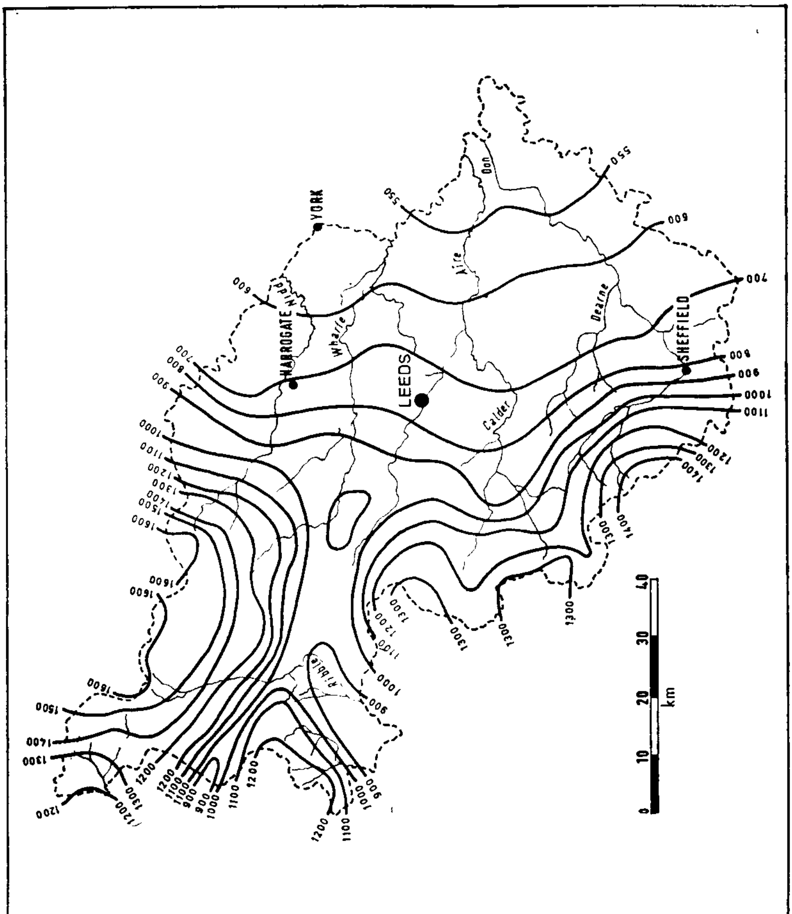

FIGURE 7—MEAN ANNUAL RAINFALL (1916–50) OF WEST YORKSHIRE DERIVED FROM EQUATION (3)

Rainfall values are in millimetres.

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A MEMORABLE RAINFALL EVENT OVER SOUTHERN ENGLAND (PART II)*

By PAULINE M. SALTER and C. J. RICHARDS

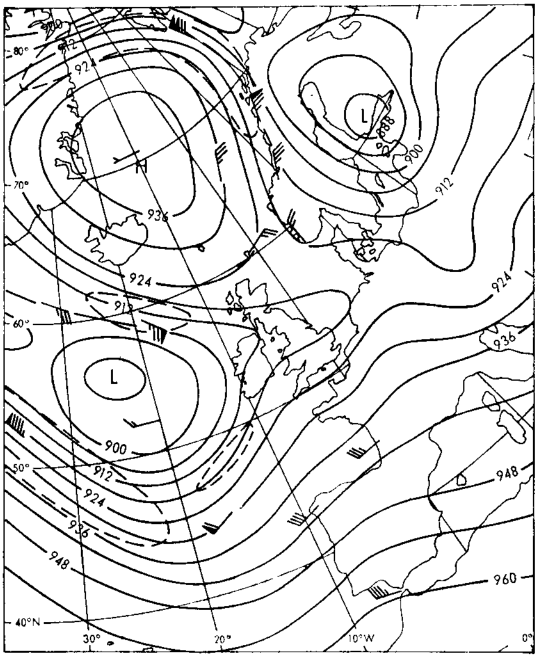
Summary. During the period 14–16 September 1968 parts of southern England experienced a memorably heavy fall of rain and substantial flooding occurred in places. The rain system was particularly intense over the south-east during the 15th. From a meteorological analysis of the situation it appears that the dominant mechanism governing the precipitation over the south-east was a pronounced convergence zone in the lower troposphere, overlaid at upper levels by a strong positive vorticity advection field operating within a narrow zone of marked horizontal wind shear. This system became slow moving on the 15th and within it a low-level inflow of potentially unstable, moisture-laden air is envisaged as leading to the 'dumping' of a heavy fall of rain over a relatively small area.

Analysis of the synoptic situation

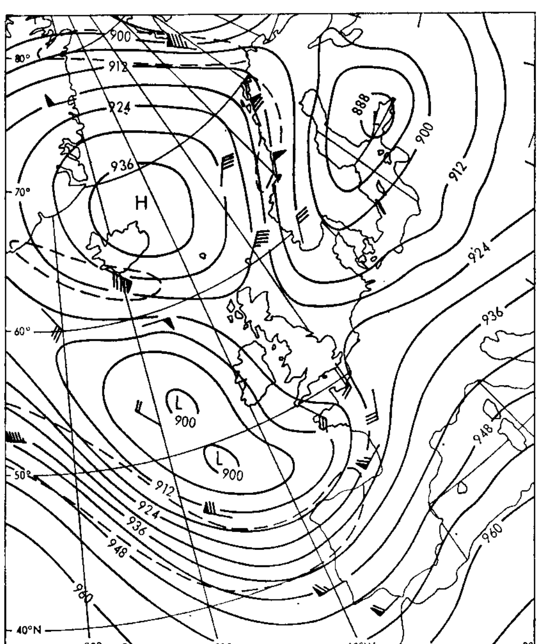
Evolution of the upper flow. The evolution of the upper flow at 300 mb during the period 13–16 September is depicted in Figure 4. During the preceding week western Europe had been dominated by a large blocking upper ridge and by 00 GMT on the 13th a large upper high cell had become cut off in the vicinity of Iceland, with a ridge extending over the North Sea. Large slow-moving upper lows covered the eastern Atlantic and Finland at this time with two well-marked jet streams in evidence. A north-westerly jet was propagating south-eastwards across the central Atlantic towards Portugal, amplifying the upper trough in this region; by 00 GMT on the 14th a considerable fall of contour height had taken place towards Biscay with a major trough becoming established at 10°W. Simultaneously, a strong polar jet round the northern flank of the upper high cell reached Scandinavia as a north-easterly current. A narrow ridge, or anticyclonic col, still covered the British Isles at 00 GMT on the 14th, but during the 14th the north-easterly jet propagated across Scotland, eventually connecting up with the cyclonic circulation around the upper low that had developed over Biscay. At the same time a south-westerly jet was strengthening over Spain and France, ahead of the increasingly confluent long-wave trough in this area. These evolutions effected a dramatic breakdown of the ridge over southern Britain, and by 00 GMT on the 15th a sharp trough had extended from the Biscay vortex across south-east Britain to Scandinavia. This trough remained quasi-stationary for much of the 15th, but by the 16th the Biscay vortex had transferred over northern France, broadening the associated trough appreciably. The south-westerly jet was displaced slowly eastwards over central Europe, whilst developments north of the British Isles cut off the north-easterly flow from Scandinavia.

The 1000–500-mb thickness pattern (Figure 1) reflects the changes in the upper-flow pattern during the period. The amplification of the upper trough near Spain on the 14th is accompanied by a tightening of the thermal gradient there and by the establishment of a marked baroclinic zone over south-west Europe. Cold advection, associated with the propagation of the north-easterly jet across Scotland, had produced a sharp thermal trough between Sweden and northern England by 00 GMT on the 15th. Over south-east England, however, thermal winds were mainly light during the 15th, suggesting that the rain system here was not much of a baroclinic feature, unlike the frontal system

* Part I appeared in the *Meteorological Magazine* for September 1974.



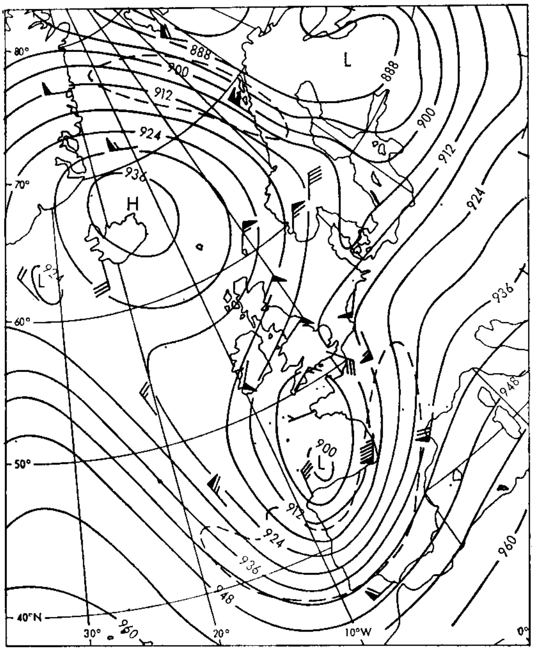
(a) 00 GMT on 13 September



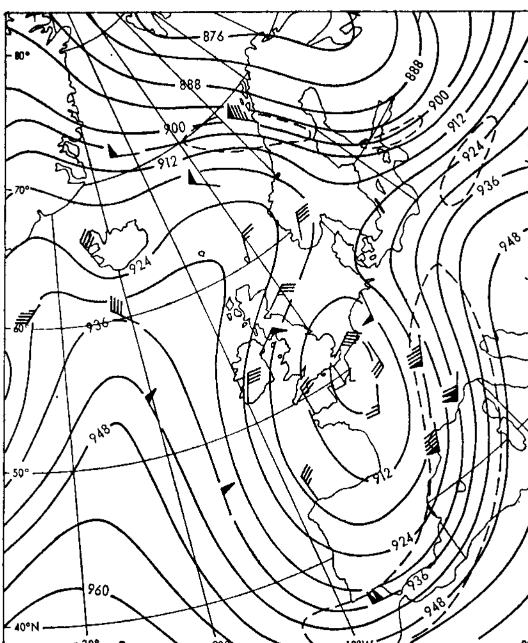
(b) 00 GMT on 14 September

FIGURE 4—300-MILLIBAR CONTOURS, 13–16 SEPTEMBER 1968

Pecked lines denote isotachs enclosing wind speed greater than 75 kt.
Contours are in geopotential decametres.



(c) 00 GMT on 15 September



(d) 00 GMT on 16 September

FIGURE 4—*continued*

Pecked lines denote isotachs enclosing wind speed greater than 75 kt.
Contours are in geopotential decametres.

over the nearby Continent, which was conspicuously associated with a jet stream aloft.

Several interesting features of the upper-flow pattern during the 14th are highlighted in the photographs taken by the then operational satellite ESSA 6. Figure 5 is a nephanalysis constructed for the area in the vicinity of the British Isles, based on orbits of the satellite between 08 and 12 GMT on the 14th.[3] The almost occluded vortex of the depression off south-west England is shown, together with its associated band of frontal cloud spiralling in towards the centre of the vortex. A tongue of clearer air, accompanied by open cellular convection, in the rear of the depression, reveals a cold advection field behind the cold front. Within the thermal trough at 10°W an area of enhanced cumulus and cumulonimbus convection is visible at 44°N 12½°W, marking an area where maximum advection of cyclonic vorticity is occurring in the mid and

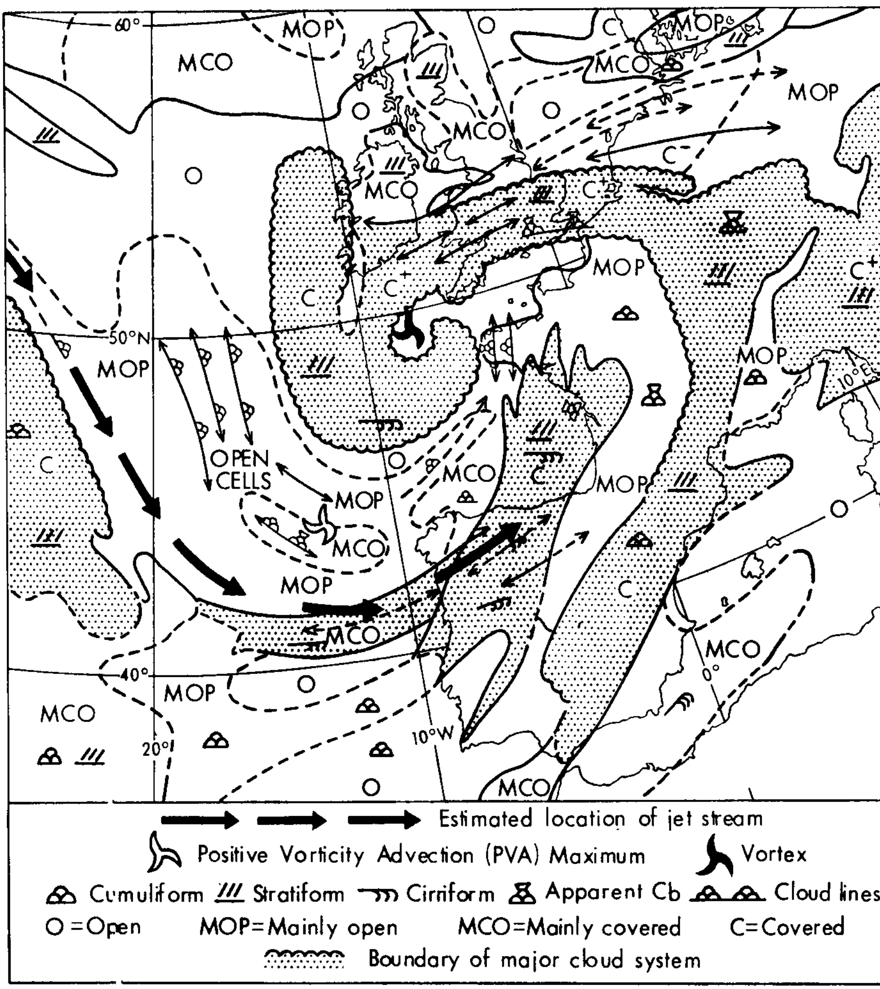
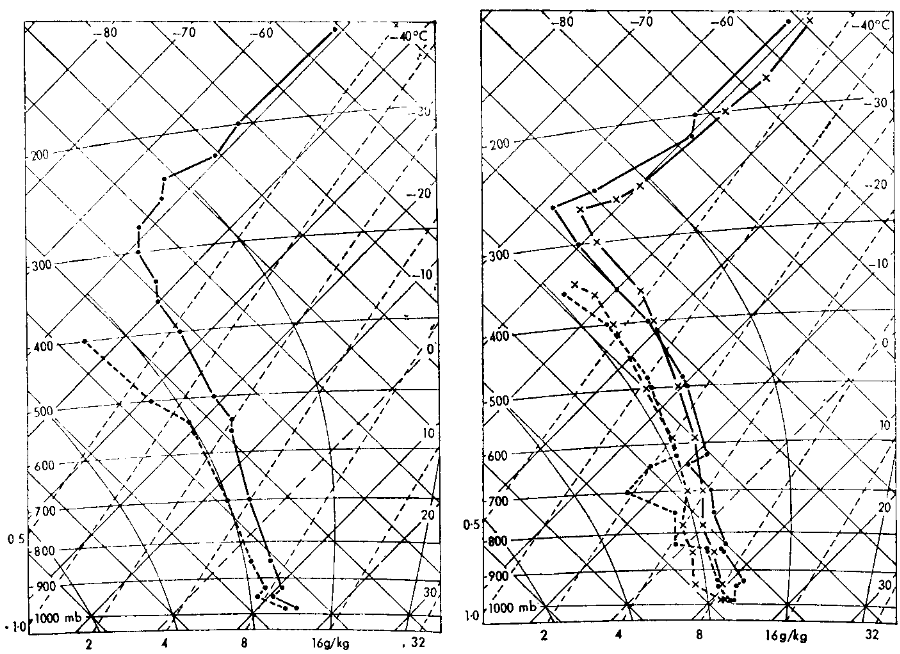


FIGURE 5—NEPHANALYSIS BASED ON CLOUD PHOTOGRAPHS FROM ESSA 6 BETWEEN 08 AND 12 GMT, 14 SEPTEMBER 1968

upper troposphere, associated with general uplift in this region. Of particular significance from the point of view of subsequent developments over northern France later in the day is the large comma-like cloud mass over the Bay of Biscay lying within the cold air mass and detached from the main baroclinic zone further east. This probably represents a much more developed centre of vorticity advection aloft and lies within the left-exit region of the south-westerly jet, then propagating across Spain and France. It reveals substantial ascent through the troposphere. The cloud mass appears stratiform with convective cells embedded in it. Fingers of probably old anvil cirrus (cirrus spissatus cumulonimbogenitus) stretch ahead over western France. Storms were reported over western France later in the afternoon of the 14th. This feature gives a visual indication of the physical and dynamical processes occurring within an area of marked cyclonic vorticity advection aloft which was approaching southern England later on the 14th.

In Figure 1, the 700-mb dew-point depression has been used to map the moisture distribution of the lower troposphere in the vicinity of the British Isles. Of interest is the formation, by the 15th, of a broad area of almost saturated air over south-west Europe which extends across south-east Britain and central Europe south of 55°N by 12 GMT on the 15th. In particular, the south-westerly jet exit region over France on the 14th is dominated by wet air in the lower troposphere.

Tephigram analysis. Figure 6 shows the temperature/dew-point soundings for Crawley between 12 GMT on the 14th and 12 GMT on the 15th. The ascent for



(a) 12 GMT on the 14th . —— . Temperature
. - - - . Dew-point

(b) 00 GMT on the 15th . —— . Temperature
. - - - . Dew-point
12 GMT on the 15th x —— x Temperature
x - - - x Dew-point

FIGURE 6—CRAWLEY TEPHIGRAMS FOR 14–15 SEPTEMBER 1968

12 GMT on the 14th (Figure 6(a)) reflects the thundery activity associated with the cold occlusion then over southern England. It is highly unstable for surface air, where screen-level wet-bulb potential temperature (θ_W) is around 14 or 15°C. Potential instability is apparent in the lowest layer up to 650 mb, at which level θ_W reaches a minimum of 11°C. With saturation θ_W (θ_S) at upper levels only a little higher, at 13°C, pronounced instability would be readily released through surface heating if not through dynamical uplift within the trough[4] and this is borne out by the vigorous convection at the time.* Vigorous electrical activity was a noted feature of this initial rain system.

Figure 6(b) (00 GMT on the 15th), shows the structure of the troposphere as it existed over south-east England before the arrival of the second system. It is moist, and though it reveals a more neutral lapse rate than on the previous day, the moist saturated adiabatic profile ($\theta_S = 14$°C) dominating the upper troposphere is interesting. It reflects the recent cumulonimbus convection of the previous day[5] and suggests relatively smooth ascent for any low-level air source with θ_W exceeding 14°C, once lifted to saturation. The energy released by the convection depends, however, on the difference between θ_W of the ascending air and θ_S aloft. (Where the adiabatic ascent characteristic of cumulonimbus convection has been in progress aloft, the lapse rate at upper levels tends towards saturated adiabatic.[5]) Surface air over south-east England was too stable to trigger off spontaneous convection during the morning of the 15th, with $\theta_W = 13$°C, so an external source of potentially unstable air must be discovered.

By 12 GMT on the 15th Crawley was lying near the heart of the convergence zone and a prolonged period of heavy rain and thunderstorms had recently ceased in the area. Though very moist at all levels, the midday ascent is more stable than 12 hours previously, particularly aloft, and this accounts for the weakening of thundery activity earlier reported within the rain system during the morning. A general cooling below 500 mb is also apparent.

The convergence zone and discussion. The convergence zone associated with the surface trough is illustrated in Figure 7 which shows streamlines of surface airflow at 09 GMT on the 15th. Pronounced convergence of air from between north-east and south-east is evident within a narrow belt over south-east England. Both speed convergence, along particular streamlines, and streamline convergence, are marked especially over the Thames Estuary and southern North Sea. This flow pattern would suggest a zone of pronounced uplift in the vicinity of the surface trough.

Trajectories of the airflow at the surface and at 700 mb are depicted in Figure 8, drawn for air converging over south-east England on the morning of the 15th. Figure 8(a) shows 700-mb trajectories, together with the distribution of θ_W at 700 mb at 12 GMT on the 14th. At this level a broad flow of air from the west of Spain crossed France during the 14th, and a branch later reached south-east England from an easterly direction. Except for a tongue of warm air ($\theta_W = 16$°C) over Belgium, air at 700 mb over France was potentially cold at 12 GMT on the 14th, with θ_W near 12°C, and it would appear that this colder air arrived over south-east England on the morning of the 15th. In

* A layer of air is potentially unstable if θ_W decreases with height through the layer. For instability to be realized this layer must be lifted to saturation. Where mixing effects are minimal, uninhibited adiabatic ascent will follow until a level is reached at which θ_S of the environment exceeds θ_W of the ascending air.

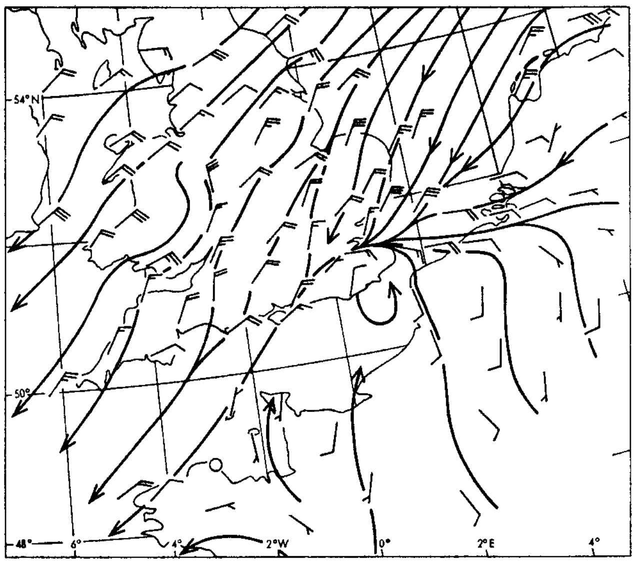


FIGURE 7—STREAMLINES OF SURFACE AIRFLOW AT 09 GMT ON 15 SEPTEMBER 1968

contrast Figure 8(b) shows surface trajectories drawn for air above the friction layer, together with the 1000-mb distribution of θ_W at 12 GMT on the 14th. Superimposed on this is a schematic representation of the 700-mb flow south of the convergence zone. At the surface, the broad, cold north-easterly current north of the convergence zone can be traced back to Finland and western Russia early on the 13th. It appears to present an effective barrier to the warm southerly flow (converging along PP in the diagram). This southerly flow can be divided into two significantly distinct streams, labelled 'A' and 'B' in Figure 8(b) and separated by the line RR. Stream A originated from a moist stagnant air mass over central Europe on the 13th and, with surface θ_W exceeding 16°C throughout a large region by 12 GMT on the 14th, this air was drawn north-westwards into the convergence zone, probably ascending over south-east England within the narrow zone separating PP and RR in this area. Warm air with $\theta_W = 15$–16°C was also present at the surface over the southern North Sea and Thames Estuary on the morning of the 15th. Stream B can be tracked back to the west of Biscay. It was drawn over France during the 14th and represents the air to the south-west of the surface trough. This stream was a little cooler than stream A.

The superimposed 700-mb flow in Figure 8(b) shows that warm, moist air in stream A ($\theta_W = 15$–16°C), flowing westwards into the convergence zone in the vicinity of south-east England, was being overridden at 700 mb by a potentially much colder stream ($\theta_W = 12$°C). The subsequent and substantial potential instability would have been readily released within the ascending branch of stream A. The fact that the upper troposphere over south-east England on the 15th tended towards increasing stability may well have accounted for the prevention of more severe thundery activity than was actually experienced. θ_S aloft was not far below the general value of θ_W within stream A.

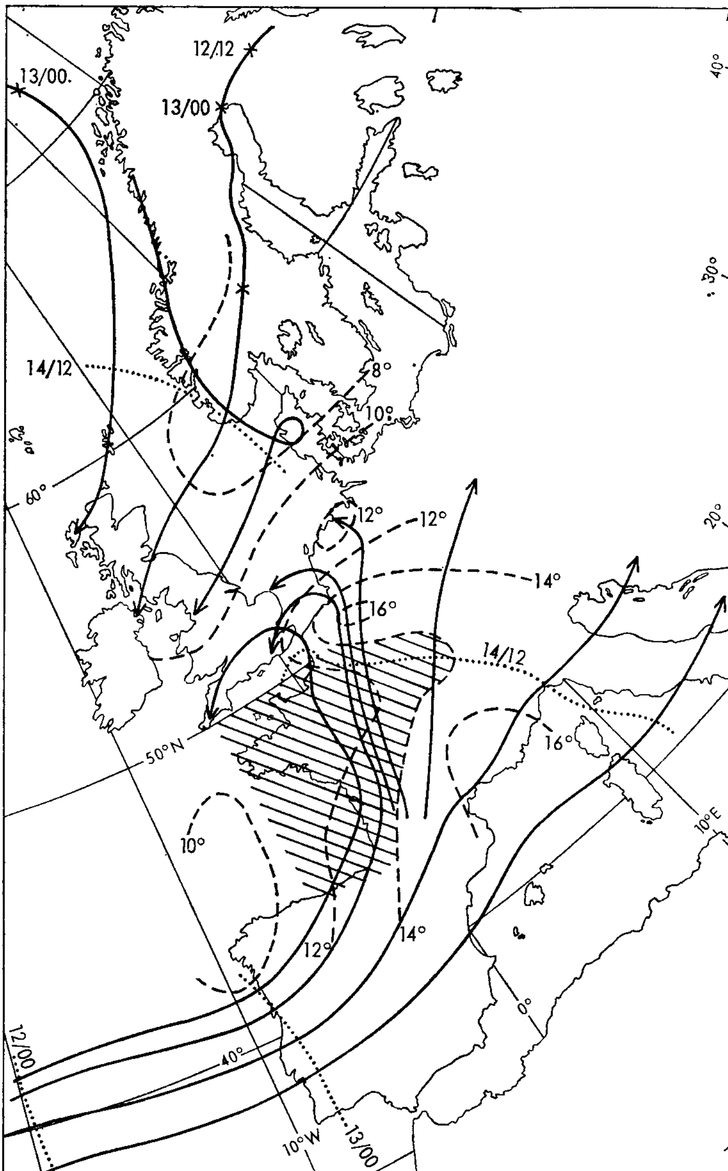


FIGURE 8(a)—700-MILLIBAR AIR TRAJECTORIES UP TO 06 GMT ON 15 SEPTEMBER 1968

Pecked lines are isothermals of θ_w at 700 mb in degrees Celsius at 12 GMT on the 14th. Hatching indicates part of area where $\theta_w < 14°C$.

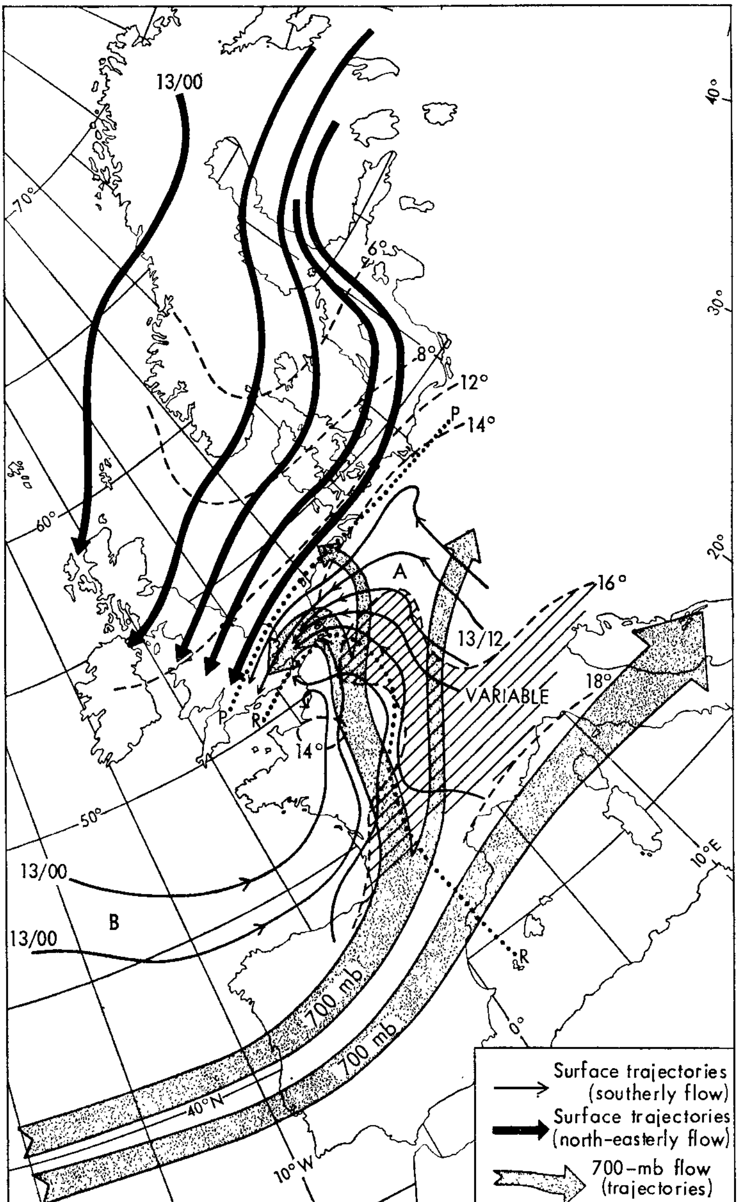


FIGURE 8(b)—SURFACE (GEOSTROPHIC) AIR TRAJECTORIES FROM 00 GMT ON 13 SEPTEMBER TO 09 GMT ON 15 SEPTEMBER 1968

Pecked lines are isothermals of θ_w at 1000 mb in degrees Celsius at 12 GMT on the 14th. Hatching indicates area where $\theta_w > 16°C$.

Figure 9, which shows the vertical wind shear over Crawley during the 15th, affords separate evidence of a differential thermal advection field within the convergence zone and the principal features of it are summarized schematically in Figure 10. At 00 GMT on the 15th warm advection was in evidence at all levels, concentrated mainly below 800 mb. Figure 9 shows warming from the east below 900 mb by 06 GMT, capped by significant cold advection between 850 and 700 mb (also at about 400 mb).[6] It will be recalled that the heavy rainfall of the morning began in the Crawley area at about 06 GMT. This wind profile is repeated at 12 GMT, the cooling below 400 mb now being apparent on the midday ascent. At 18 GMT the advection field becomes weak at all levels, reflecting the westward passage of the trough axis over Crawley at about this time. Crawley's wind profile is imitated over Hemsby later on the 15th, though to a lesser degree, and can be associated with the approach of the convergence zone towards East Anglia at this time.

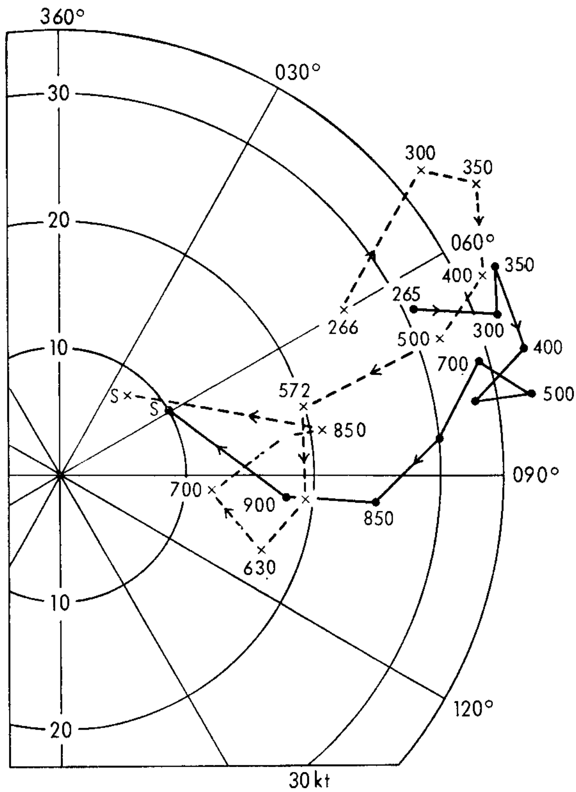


FIGURE 9—HODOGRAPH OF THE VERTICAL WIND PROFILE OVER CRAWLEY ON 15 SEPTEMBER 1968

• —— • 06 GMT x - - - x 12 GMT

Conclusions. During the analysis of the upper flow, emphasis was placed on the developments that occurred in the vicinity of the British Isles during the 14th and 15th. The propagation of two jet streams effected the breakdown of an upper ridge over the country during the 14th, substituting for it a sharp

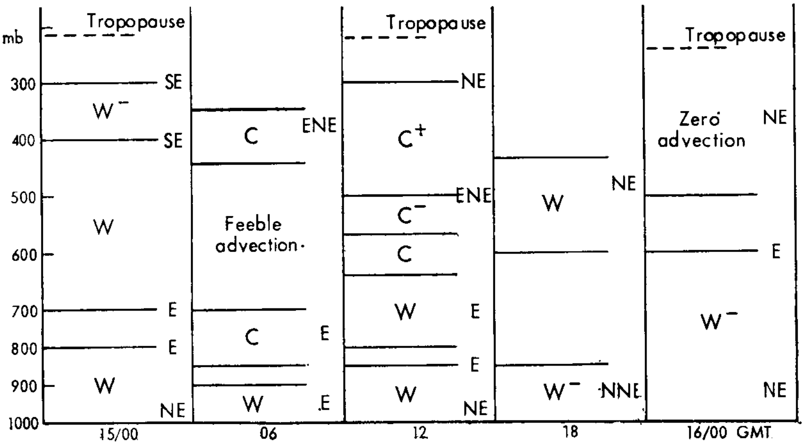


FIGURE 10—THERMAL ADVECTION AND RELATIVE STABILITY ANALYSIS OF THE AIR MASS OVER CRAWLEY ON 15 SEPTEMBER 1968 TAKEN FROM RADIOSONDE AND PILOT WIND DATA

W denotes warm advection, C cold; + and – are relatively strong and relatively weak advection fields respectively. Wind directions are approximate. Lowest C in middle column should read C+.

trough by 00 GMT on the 15th, orientated north-east to south-west across south-east Britain. This trough can be described as a 'shear-zone' that exhibited pronounced horizontal wind shear across its axis, a jet-exit region common to both north-easterly and south-westerly jets in which marked cyclonic vorticity advection was occurring, and a zone where pronounced ascent of air would be expected on purely dynamical grounds. The shear-zone became a stationary feature of the atmosphere for approximately 24 hours. These developments are summarized in Figure 11.

The associated low-level convergence zone was an equally notable feature. A low-level current of warm, moisture-laden air, drawn westwards into the convergence zone, was overridden in the lower middle troposphere by potentially colder air. In an environment already experiencing marked dynamical uplift this potential instability would have been readily released. Throughout the period of continuous heavy rainfall, the vertical wind profile of radiosonde ascents independently revealed the presence of a differential thermal advection field in the lower troposphere. The intensity of convection was probably limited by the small depression of θ_S aloft over south-east England relative to θ_W of the inflowing warm low-level air. The rainfall distribution shown in Figure 3 silhouettes vividly the influence of the surface convergence zone. The axis of the heaviest precipitation virtually coincides with that of the convergence zone when it became slow moving during the morning and afternoon of the 15th. The isohyet gradient on the south of this zone is particularly pronounced in places. As the shear-zone weakened by the 16th, the dynamical mechanism described above disappeared. Precipitation thus ceased to be as heavy or as organized as it had been on the 15th.

Several factors that are regarded as meteorologically significant have been discussed. The rainfall event was characterized by the coincidence of these

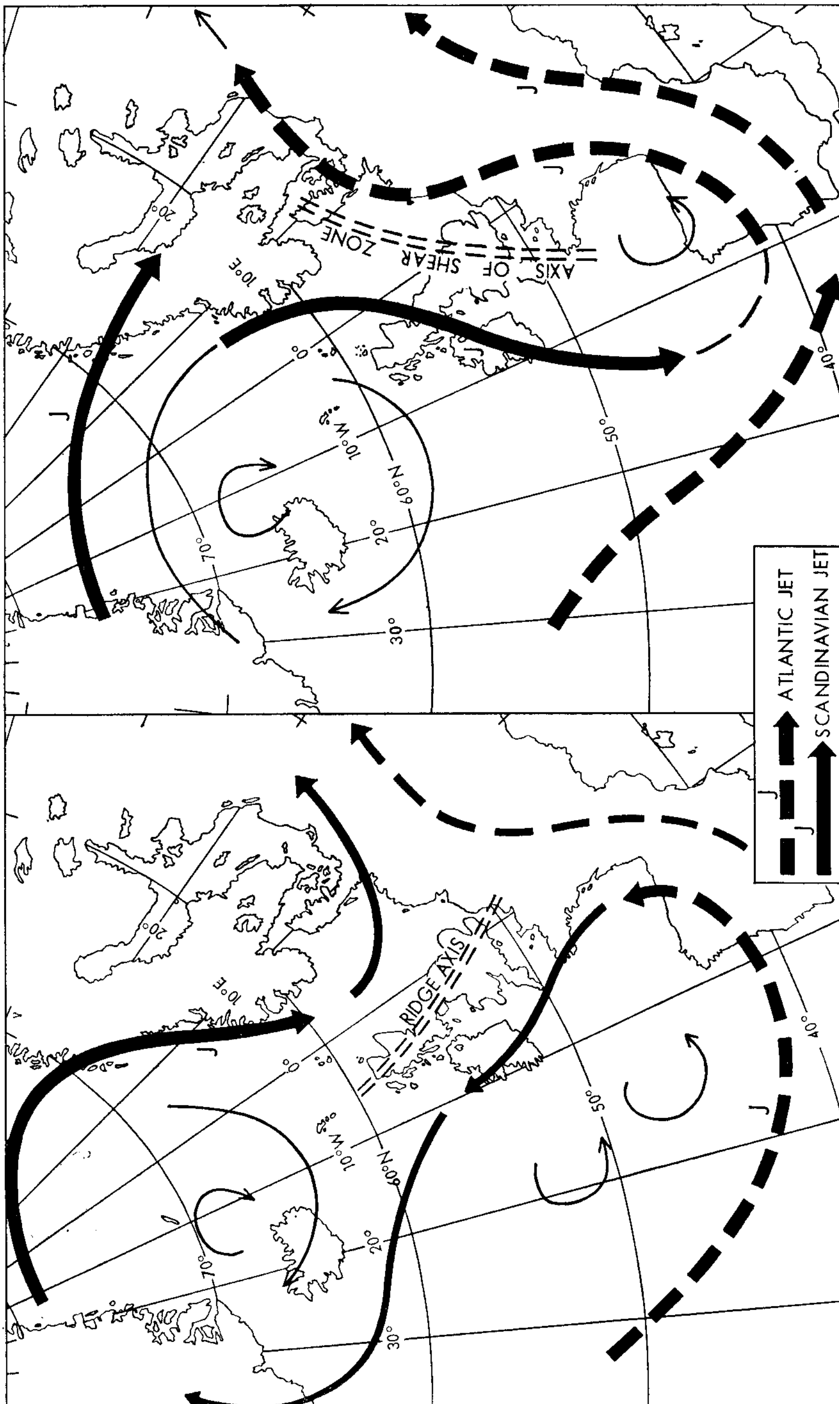


FIGURE 11—EVOLUTION OF THE UPPER FLOW PATTERN NEAR THE BRITISH ISLES, 14–15 SEPTEMBER 1968

(a) 00 GMT on the 14th (b) 00 GMT on the 15th factors, each of which isolated out of context, would not be considered exceptional. However, the strong cyclonic vorticity advection field operating within the shear-zone aloft must be regarded as the controlling influence. Other factors must be viewed in this context, in which a quasi-stationary system allowed the dumping of a substantial fall of rain over a relatively small area, an area almost of mesoscale dimensions.

Acknowledgments. The authors are indebted to the River Authorities named in the text, to the Thames and Lee Conservancies, and to the Greater London Council, for information supplied about flooding and damage in their areas.

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A NOTE ON AN INDEX OF TRAPPING EFFICIENCY OF SMOKE PARTICLES IN THE LAYER SURFACE TO 1000 MILLIBARS OVER ATHENS AT NIGHT

By JOHN G. DIKAIAKOS

Climatological Laboratory of the University of Athens

Summary. An index is proposed of 'the mean monthly trapping efficiency of smoke particles in the layer surface to 1000 millibars over Athens at night'. The index may readily be calculated from readings at the surface and 1000 mb. Smoothed mean monthly values of the index and of the nocturnal concentration of smoke particles show close agreement.

Introduction. Measurements of air pollution giving mean concentrations of smoke particles in $\mu g/m^3$ were made by the National Meteorological Institute of Athens (NMIA) on almost all nights in 1971 between 22 and 06 GMT (00–08 Local Mean Time). The measurements were made at the NMIA on top of Nymphe's hill (107 m above mean sea level) which lies almost in the centre of Athens and is surrounded by roads carrying a great deal of traffic. This point lay under or close to 1000 mb throughout the period and the measurements are expected to be representative of the layer under discussion.

For all practical purposes the smoke particles may be considered to originate from buses and cars. The number of these vehicles and hence the emission of smoke do not change significantly from month to month.

The night-time wind blows from varying directions with very low speeds. Mean monthly values varied during 1971 from 4·63 m/s to 1·56 m/s with a mean annual wind speed of 3·17 m/s. The layer from the surface to 1000 mb was on average stable with positive vertical gradients for all mean monthly values of potential temperature.

The average monthly degree of pollution is expected to depend mainly on the average monthly rate of upward transport of smoke particles through the layer and consequently upon the average monthly values of both potential temperature and the vertical gradient of wind speed within the layer.

With these considerations in mind an index was sought, expressed in terms of the above gradients, which would measure the 'trapping efficiency' and which would be strongly and positively correlated with the degree of air pollution.

The index. Mean monthly values of the index are symbolized by δ_i (i = 1 for January, 2 for February, ... 12 for December) and are calculated as follows:

$$\delta_i = 10^2 \times k_i^{-1}(\overline{\Delta\theta/h})_i \, (\overline{\Delta u/h})_i^{-1} \qquad (\text{s m}^{-1}\,\text{degC}^{-1}) \qquad \ldots (1)$$

where

$$k_i = \frac{1}{n_i}\sum_{j=1}^{n_i}(t_{1000} + t_s)_j\,(\theta_{1000} + \theta_s)_j/4 \qquad (\text{degC K}) \qquad \ldots (2)$$

$$(\overline{\Delta\theta/h})_i = \frac{1}{n_i}\sum_{j=1}^{n_i}(\theta_{1000} - \theta_s)_j/h_j \qquad (\text{K m}^{-1}) \qquad \ldots (3)$$

$$(\overline{\Delta u/h})_i = \frac{1}{n_i}\sum_{j=1}^{n_i}(u_{1000} - u_s)_j/h_j \qquad (\text{s}^{-1}) \qquad \ldots (4)$$

and

t is temperature in degrees Celsius,
θ is potential temperature in kelvins,
u is wind speed in metres per second,
h is depth of the layer, surface to 1000 mb.

Subscripts s and 1000 indicate the values at the surface and at 1000 mb respectively; n_i is the monthly number of air-pollution measurements and radiosonde ascents (made at Hellinikon, about 10 kilometres from NMIA), and j takes the values 1,2, ... n_i.

The mean monthly degree of air pollution in the layer is calculated from:

$$N_i = \frac{1}{n_i}\sum_{j=1}^{n_i} N_j \qquad (\mu\text{g/m}^3) \qquad \ldots (5)$$

where N_j is the mean nightly concentration of smoke particles.

Presentation of data and discussion. Table I gives the values of δ_i and N_i calculated from equations 1–5, after being smoothed by the formula:

$$\bar{x}_i = (x_{i-1} + x_i + x_{i+1})/3 \qquad \ldots (6)$$

where as before x_1 denotes January, x_2 February ... x_{12} December and $x_{13} = x_1$.

Figure 1 shows the graphs of these smoothed means. There is a close similarity between the curves, the minimum of both falling in August, with a secondary minimum in February. The maximum for $\bar{\delta}_i$ occurs in December and that for $\bar{N}_i$ in November with secondary maxima in April and May respectively.

From Figure 2 it is seen that the points $\bar{\delta}_i$ and $\bar{N}_i$ are closely approximated by the line of least squares fit:

$$\bar{N}_i = 38{\cdot}53 + 6{\cdot}89\,\bar{\delta}_i.$$

The correlation coefficient between $\bar{N}_i$ and $\bar{\delta}_i$ has the very high value of +0·94.

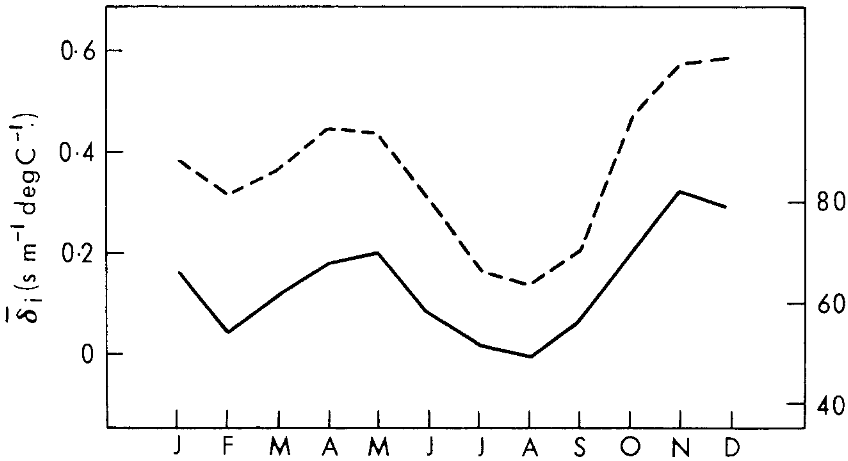

FIGURE 1—ANNUAL CYCLES OF $\bar{\delta}_i$ (– – –) AND $\bar{N}_i$ (———)

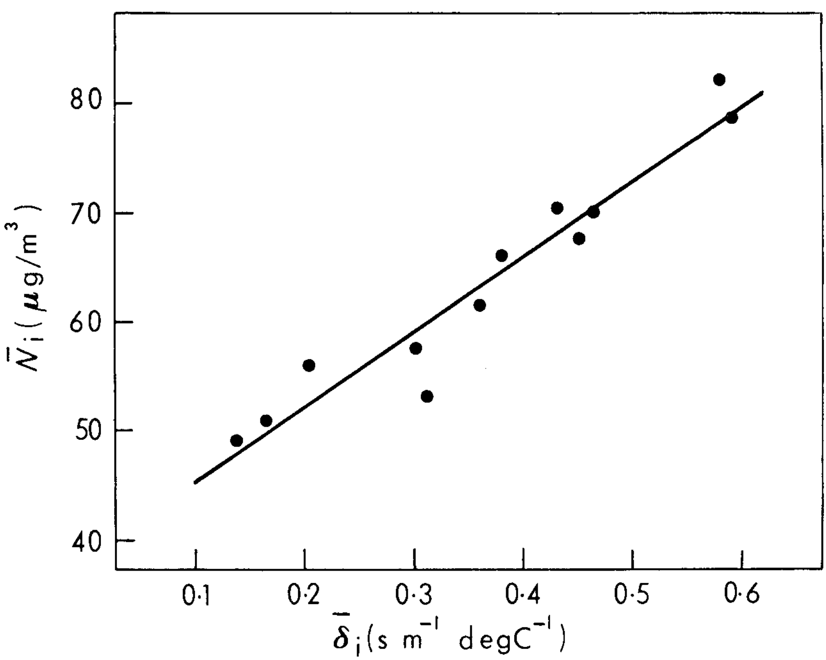

FIGURE 2—$\bar{N}_i$ AGAINST $\bar{\delta}_i$

TABLE I—VALUES OF $\bar{\delta}_1$ (s m^{-1} degC^{-1}) AND $\bar{N}_1$ (μg/m^3)

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
$\bar{\delta}_1$	0·384	0·312	0·362	0·447	0·434	0·304	0·167	0·137	0·205	0·466	0·580	0·591
$\bar{N}_1$	66·2	53·4	61·6	67·8	70·1	57·8	51·2	49·0	56·6	69·8	82·6	79·1

Conclusions. Although the index is based upon radiosonde data made once nightly at Hellinikon Airport two hours after midnight, it gives a good measure of the trapping efficiency of smoke particles, and it is hoped that it will prove a useful tool in dealing with the problems of air pollution in Athens at night.

Acknowledgement. The author wishes to express his deep thanks to Professor L. N. Carapiperis who supplied him with the measurements of air pollution made at NMIA.

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MR F. J. PARSONS, M.B.E., COMPLETES 60 YEARS OF OBSERVING

Mr F. J. Parsons, the meteorological observer at the County Observatory, Ross-on-Wye, completed his 60th year as a meteorological observer in July 1974. Mr Parsons commenced his duties at the Observatory in July 1914 and, apart from absence on war service during the First World War, has personally maintained, without a break, a programme of meteorological observations and summaries for the Observatory.

A ceremony to mark the completion of a century of weather observations at the station was held on 17 July 1959. This ceremony was presided over by the Chairman of the Urban District Council. Those attending included the Lord Lieutenant of Herefordshire and representatives from the Royal Meteorological Society, the Meteorological Office and local authorities. A number of former and contemporary assistant observers were also present.

Mr Parsons completed 50 years as an observer in July 1964 and a letter of congratulations was sent to him by Sir Graham Sutton, the then Director-General of the Meteorological Office. In June 1965 the M.B.E. was bestowed by Her Majesty the Queen in recognition of his long and valuable service.

His enthusiasm has ensured for Ross-on-Wye a series of weather records, the excellence of which is equalled at few places in the British Isles, and which is of great value both to the World Meteorological Organization and to the local agricultural community. The high reputation of the Observatory has led to its being classed as a key climatological station of the Meteorological Office, and in 1966 it was adopted as a Reference Climatological Station of the World Meteorological Organization.

Mr Parsons celebrated his 83rd birthday on 14 July 1974.

LETTER TO THE EDITOR

551.591.36

Note on errors that may be induced by using visibility observations taken at greater than hourly intervals

In their paper in the *Meteorological Magazine* for April 1974 Messrs Hinz and Carroll remark at the foot of page 106 that 'Shellard's comment that "very satisfactory estimates of annual frequency can be obtained by using observations made at 0300, 0900, 1500 and 2100 GMT" must be evaluated in the of light what is "very satisfactory" '. This seems hardly a fair comment because the authors have quoted only a part of my table, namely that concerned with very low visibilities (where the samples are small) to which my statement was certainly not intended to apply in isolation.

The figures in Hinz and Carroll's Table I are in fact in very good agreement with those given in my 1959 paper in showing that for visibilities greater than about 50 yards the estimates based on three-hourly, or six-hourly observations are very close to those based on hourly observations.

Incidentally there is a mistake in the heading to column 4 of the table near the bottom of p. 106 of Hinz and Carroll's paper where 'Three-hour' should read 'Six-hour'.

H. C. SHELLARD

Meteorological Office,
Bracknell.

OBITUARY

It is with regret that we have to record the untimely death on 26 July of Mr G. F. Trowell, who has regularly taken climate observations for the past 25 years at East Malling Research Station under the Agrometeorological Scheme.

His intelligent interest in weather recording has been demonstrated in his published papers on various aspects of the climate of East Malling.

CORRECTION

Meteorological Magazine, April 1974, p. 106. In the short table at the foot of the page, the heading 'Three-hour observations' should read 'Six-hour observations'.

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NOTICES

It is requested that all books for review and communications for the Editor be addressed to the Director-General Meteorological Office, London Road, Bracknell, Berkshire, RG12 2SZ, and marked 'For Meteorological Magazine'.

The responsibility for facts and opinions expressed in the signed articles and letters published in this magazine rests with their respective authors.

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