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THE ESTIMATION OF SOIL MOISTURE DEFICITS

By J. GRINDLEY

Summary.—A description is given of a method of estimating current values of soil moisture deficits over Britain as a routine aid for the river authorities and engineers responsible for flood defence systems and water resources. The method allows deficit estimates to be prepared in map form for Britain, with supplementary tabular statements for major river catchment areas. The estimates are based on observed rainfall and estimated evaporation at a network of 176 stations covering Britain. The calculations allow for variation in the rate of evaporation during the month, and for variation of estimated actual evaporation according to the type of vegetation in the catchment area. Special circumstances are discussed affecting the calculation of the restitution of soils to field capacity. The maps of estimates are prepared monthly or fortnightly taking account of the daily values of rainfall and evaporation. Objective estimates can also be obtained for the probability of deficits being made good by a given date.

Introduction.—Regular estimates* of soil moisture deficits in map form and as a tabular statement for major river catchment areas have been prepared by the United Kingdom Meteorological Office and distributed at a small charge to authorities in Great Britain since September 1962.

The estimates were originally intended as aids to flood warning, since the risk of flooding after heavy rain was considered to increase sharply once the 'cushioning' effect of spare moisture capacity in the rooting zone of vegetation had been eliminated. The estimates of soil moisture deficit quickly found favour also with water supply engineers who were interested in the extent of any delay in the increase of run-off and in the establishment of deep percolation: these are factors which govern the replenishment of reservoirs, surface and underground. (Run-off is that part of the precipitation which is discharged in surface streams. Deep percolation refers to the downward passage of surface water through the soil to the permanent water table where the soil is persistently saturated with water.)

The work had its origin in a paper by Grindley[1] in which an attempt was made to forecast the date of first appreciable run-off in the United Kingdom following the very dry summer of 1959.

The derivation of soil moisture deficit estimates.—Basically, the estimates of soil moisture deficit are obtained by taking the difference between rainfall and evaporation. The rainfall values used are those observed at the station. The evaporation estimates for the summer 6 months April–September are based on a shortened version[2] of the well-known Penman formula.[3] In the shortened version monthly departures from average sunshine are multiplied

*London, Meteorological Office. Estimated soil moisture deficits. Issued periodically by the Meteorological Office (Agriculture and Hydrometeorology Branch).

by a weighting factor and added algebraically to average monthly evaporation. Estimates of average evaporation are used for the winter months October–March when, however, evaporation is generally small in the British Isles. In view of their avowed purpose as aids to flood warning, estimates of soil moisture deficits must be prepared as quickly as possible and, at present, time is not available for the more desirable procedure of calculating evaporation using the standard Penman formula.

When evaporation exceeds rainfall, vegetation has to draw on moisture reserves in the soil to satisfy the requirements of transpiration and in this way soil moisture deficits are set up (see Table I).

TABLE I—SIMPLE EXAMPLE OF SOIL MOISTURE DEFICIT

Month	Rainfall	Evaporation	Soil moisture deficit
		inches	
April	2·09	1·86	nil
May	3·93	3·30	nil
June	1·68	3·55	1·87

Clearly a slight moisture deficit will arise (even in winter) on any day when precipitation is nil or daily evaporation exceeds daily rainfall. Such deficits may be temporary and quickly eliminated by a succeeding day or days in which precipitation exceeds moisture deficit plus evaporation on the succeeding day or days, or they may persist and accumulate. If we are dealing only with monthly totals, the fact that such an accumulation is not taken into account may lead to serious error in the calculated total soil moisture deficit over a season. For example, if a dry period, possibly of up to two weeks duration, occurs in the second half of a month in which the precipitation in the first half of the month had already exceeded evaporation for the whole month, then the excess precipitation in the first part of the month must be assumed to have run off or percolated to permanent ground water (the water retained in the zone of permanent saturation below the water table). It is then necessary to estimate evaporation over the period of dryness, and to make allowance as required for different rates of evaporation in different parts of the month. This is particularly important in spring months when evaporation rates normally increase rapidly.

If, in the example quoted, the last 11 days of May are assumed to be dry, the excess precipitation in the first part of the month must be counted as lost to permanent ground water or run-off. Evaporation over the last 11 days then represents the excess of evaporation over rainfall and a deficit would be set up from the 20th. It is estimated that 39 per cent of the May evaporation normally occurs in the last 11 days. In this example, 39 per cent of the total evaporation (3·30 in) is 1·29 in. Thus the soil moisture deficit at the end of May would be 1·29 in instead of nil and the deficit at the end of June would be 3·16 in and not 1·87 in.

Allowance for actual evaporation falling below potential.—In assessing soil moisture deficits it is necessary to take into account the fact that vegetation has increasing difficulty in extracting moisture from the soil as accumulated evaporation becomes increasingly greater than accumulated precipitation. The question of the manner and extent to which evaporation rates fall below the potential rate when moisture supplies become limited is a controversial one and has been discussed extensively in the literature.

The method adopted is that proposed by Penman[4] in which it is assumed that moisture is readily extractable by root systems up to a specified limit (the so-called 'root constant', which varies with extent and depth of root systems), approximately a further inch depth of soil moisture is less easily extracted and beyond that point any further extraction becomes difficult. The graph published as Figure 1 in Penman's paper[4] has been expressed in tabular form for ease of reference. Typical figures for a root constant of 3 in are:

Potential evaporation (in)	4·00	5·00	6·00	7·00	10·00
Actual evaporation (in)	3·92	4·30	4·46	4·54	4·79

Thus when the potential evaporation changes from 5·00 in to 6·00 in, the actual increased amount of moisture extracted from the soil through a plant system with a root constant of 3 in is 0·16 in although the potential increase is 1 in.

The calculation of areal soil moisture deficits.—Because the preparation of national maps of soil moisture deficit was conceived as an aid to flood warning it was necessary to consider how soil moisture deficits might vary over an area.

Most catchment areas of more than a few square miles in extent will contain a variety of types of vegetation each with its appropriate root constant. It is inexpedient to adopt exact root constants for each type and, indeed, without experimental evidence, the root constant appertaining to a particular type of vegetation cannot be known. Therefore, in the preparation of the soil moisture deficit maps, a system has been adopted of multi-capacity basin accounting based on that proposed by Penman[5] for the Stour catchment in East Anglia.

It is assumed that each station is representative of a typical cross-section of catchment area in which 50 per cent of the area is covered by short-rooted vegetation (e.g. grass) to which a root constant of 3 in is assigned, 30 per cent of the area is covered by long-rooted vegetation having a root constant of 8 in and 20 per cent of the area is riparian, i.e. the permanent ground water is so near the soil surface that roots can draw on moisture at the potential rate at all times, evaporation is never inhibited and no soil moisture deficits can be set up. This last assumption is almost certainly not true. Except where permanent ground water is within a few inches of the soil surface, a zone of aeration is likely to exist where roots can draw on soil moisture before or at the same time as they draw on ground water. Because of the limited extent of the zone of aeration and the tendency for capillary rise of moisture from the permanent ground water, it is considered that such soil moisture deficits as may exist will be small and they are ignored therefore in assessing areal soil moisture deficit, i.e. soil moisture deficits are assumed to exist over a maximum of 80 per cent of the area.

These proportions and root constants might need to be varied for any specific catchment area and some indication of the extent to which variation is required can be obtained from land utilization surveys, inspection in the field, maps of ground water level, etc.

The procedure in Table I for a simple estimation of soil moisture deficit can be modified as shown in Table II to take account of various zones in a catchment area.

TABLE II—CALCULATIONS OF DEFICITS FOR CATCHMENT AREA (JUNE–SEPTEMBER)

Month	Rainfall	Evaporation		Accumulated soil moisture deficits			
	R	E	$R–E$	C_p inches	C_8	C_3	Catchment area
June	1·68	3·55	− 1·87	1·87	1·87	1·87	1·50
July	1·45	4·25	− 2·80	4·67	4·67	4·22	3·51
August	0·54	3·45	− 2·91	7·58	7·58	4·59	4·57
September	—	2·00	− 2·00	9·58	9·19	4·75	5·13

Here, C_p indicates the accumulated potential soil moisture deficit, C_8 the accumulated deficit over the zone with long-rooted vegetation with root constant 8 in, and C_3 the accumulated deficit over the zone with short-rooted vegetation with root constant 3 in. The accumulated total for C_8 and C_3 is adjusted where necessary to allow for actual evaporation falling below the potential.

At the end of August the actual soil moisture deficit over the area with short-rooted vegetation is 2·99 in less than the potential. The catchment area deficit, allowing for the fact that a zero deficit is assumed over the 20 per cent of the area considered riparian, is 4·57 in.

Note that at the end of September, the accumulated excess (9·58 in) of evaporation over rainfall has exceeded the 8-in root constant representing the moisture readily extractable by long-rooted vegetation. The actual evaporation and hence soil moisture deficit over this zone becomes less than the potential.

The amount by which actual evaporation from short-rooted vegetation fell below the potential in each month would be: July 0·45 in, August 2·54 in, September 1·84 in.

The restitution of soils to field capacity.—When rainfall again starts exceeding evaporation, usually in autumn if monthly totals only are considered, the soil moisture deficits are reduced by the amount by which rainfall exceeds evaporation. In this connexion it should be noted that the excess of rainfall over evaporation will make an almost immediate contribution to run-off over the riparian zone and that the zone with short-rooted vegetation (C_3) will have deficits made good and hence be contributing to run-off before zone C_8. The assumption of an almost immediate contribution to run-off is supported by the response of streams to precipitation for it is an observed fact that rainfall of quite moderate amount will increase stream flow to some extent even though substantial soil moisture deficits may exist over the catchment generally.

It is perhaps pertinent to point out that in the estimation of soil moisture deficits a basic assumption is implied that when a deficit already exists all precipitation is either evaporated, used to make good soil moisture deficits or eventually percolates to permanent ground water, i.e. there is no surface run-off. Such an assumption is demonstrably false for rugged upland catchments with steep slopes where, however, owing to the persistently high rainfall, soil moisture deficits rarely persist for more than a few days or, at most, weeks. The assumption may also not be true over much flatter areas of southern and eastern England in certain circumstances, e.g. in high-intensity thunderstorm rainfall. Even in these circumstances, however, surface flow without any wetting of the sub-surface seems unlikely: much of the run-off in this case is likely to occur from the riparian area and from sub-surface flow where a certain amount of the percolate will have contributed to restoration of soil moisture. Wherever purely surface run-off occurs, the soil moisture deficits will be underestimated by the amount of the run-off.

When rainfall exceeds evaporation the difference is deducted from the existing soil moisture deficits over each zone until zero deficit is reached; the soils are then said to be at field capacity, i.e. they contain the maximum amount of moisture which they are capable of holding and any subsequent excess precipitation percolates to permanent ground water or runs off. For example, the soil moisture deficits obtained at the end of September in Table II may be reduced in succeeding months (see Table III).

TABLE III—CALCULATION OF RESTITUTION OF FIELD CAPACITY (SEPTEMBER–DECEMBER)

	R	*E*	*R–E*	C_p *inches*	C_8	C_3	Catchment area
September	—	2·00	− 2·00	9·58	9·19	4·75	5·13
October	1·00	0·84	+0·16	9·42	9·03	4·59	5·00
November	5·50	0·25	+5·25	4·17	3·78	0	1·13
December	4·00	0·10	+3·90	0·27	0	0	0

Soils reach field capacity in November over the short-rooted zone and in December over the long-rooted zone when soil moisture deficits are everywhere eliminated.

A special case arises when evaporation again exceeds rainfall after a period of decreasing soil moisture deficit. The mechanism of replenishment is that the soil is replenished from the top downwards and it is assumed that such excess water is within easy reach of the root system and until it is used up it is freely available for evaporation by vegetation. Two cases then arise : in Table IV (*a*) the excess of evaporation over rainfall in the later period does not exceed the excess of rainfall over evaporation in the earlier period, in which case the depletion of soil moisture reserves continue at the potential rate; in Table IV (*b*) the excess of evaporation over rainfall in the later period does exceed the excess of rainfall over evaporation in the earlier period, in which case the depletion of soil moisture reserves is curtailed after the consumption of excess rainfall in the upper layers of the soil.

TABLE IV—CALCULATION OF REPLENISHMENT

(*a*) First example

	R	*E*	*R–E*	C_p *inches*	C_8	C_3	Catchment area
July	1·45	4·25	− 2·80	4·67	4·67	4·22	3·51
August	4·54	3·45	+1·09	3·58	3·58	3·13	2·64
September	1·50	2·00	− 0·50	4·08	4·08	3·63	3·04

(*b*) Second example

	R	*E*	*R–E*	C_p *inches*	C_8	C_3	Catchment area
July	1·45	4·25	− 2·80	4·67	4·67	4·22	3·51
August	4·54	3·45	+ 1·09	3·58	3·58	3·13	2·64
September	—	2·00	− 2·00	5·58	5·58	4·40	3·87

In Table IV (*b*) the soil moisture deficit over zone C_3 at the end of September is adjusted for the root constant and is 4·40 in, not 5·13 in. In all subsequent calculations, so long as accumulated potential soil moisture deficit does not exceed the peak of 5·58 in, evaporation and hence depletion of soil moisture reserves may continue at the potential rate.

So far, attention has mainly been directed to the calculation of soil moisture deficits using rainfall and evaporation totals at the end of the month. Experience has shown that the distribution of rainfall within the month may be such that estimates of soil moisture deficit can be considerably in error by using end of month totals only. For example, consider the case where potential soil moisture deficits at the end of August are 6·00 in and deficits over the short-rooted zone 4·43 in. If now the total rainfall for September were 3 in and total evaporation 2 in, the apparent soil moisture deficits would be:

	R	*E*	*R–E*	C_p *inches*	C_8	C_3	Catchment area
September	3·00	2·00	+1·00	5·00	5·00	3·43	3·21

If, however, all the September rainfall had fallen on the last day of the month, an estimate of soil moisture deficit on a daily basis would provide the following values:

	R	*E*	*R–E*	C_p *inches*	C_8	C_3	Catchment area
1–29 Sept.	—	1·95	− 1·95	7·95	7·95	4·62	4·69
30 Sept.	3·00	0·05	+2·95	5·00	5·00	1·67	2·33

That is, the true catchment area deficit at the end of September would be 2·33 in not 3·21 in. For this reason, estimates of soil moisture deficit are now prepared by taking account of daily rainfall and evaporation.

The preparation of soil moisture deficit maps.—Usually soil moisture deficit maps are issued about the 10th of the month in summer and twice monthly in autumn and winter until deficits are made good. The maps are considered to be up to date to the morning on which they are prepared.

The maps are based on observed rainfall and estimated evaporation at a network of 176 stations covering Great Britain. The data for most of these stations are received monthly and the soil moisture situation at the end of the month at each of these stations is calculated as soon as data become available. Estimates of soil moisture deficit for the period between the end of the previous month and the 10th or later date in the current month are obtained by using values of daily rainfall, which are available up to date for 45 *Daily Weather Report** stations, supplemented by the latest information for a similar number of *Weekly Weather Report** stations. Accumulated rainfall for the period from the 1st to the date of preparation of map is expressed as a percentage of the annual average at each of these stations and percentage values are plotted and lines of equal percentage are drawn. For each one of the 176 stations for which soil moisture deficit estimates are prepared a percentage value is obtained from the map and applied to the annual average rainfall for the station to obtain a value in inches for the period. Average evaporation

*London, Meteorological Office. *Daily Weather Report* and *Weekly Weather Report.*

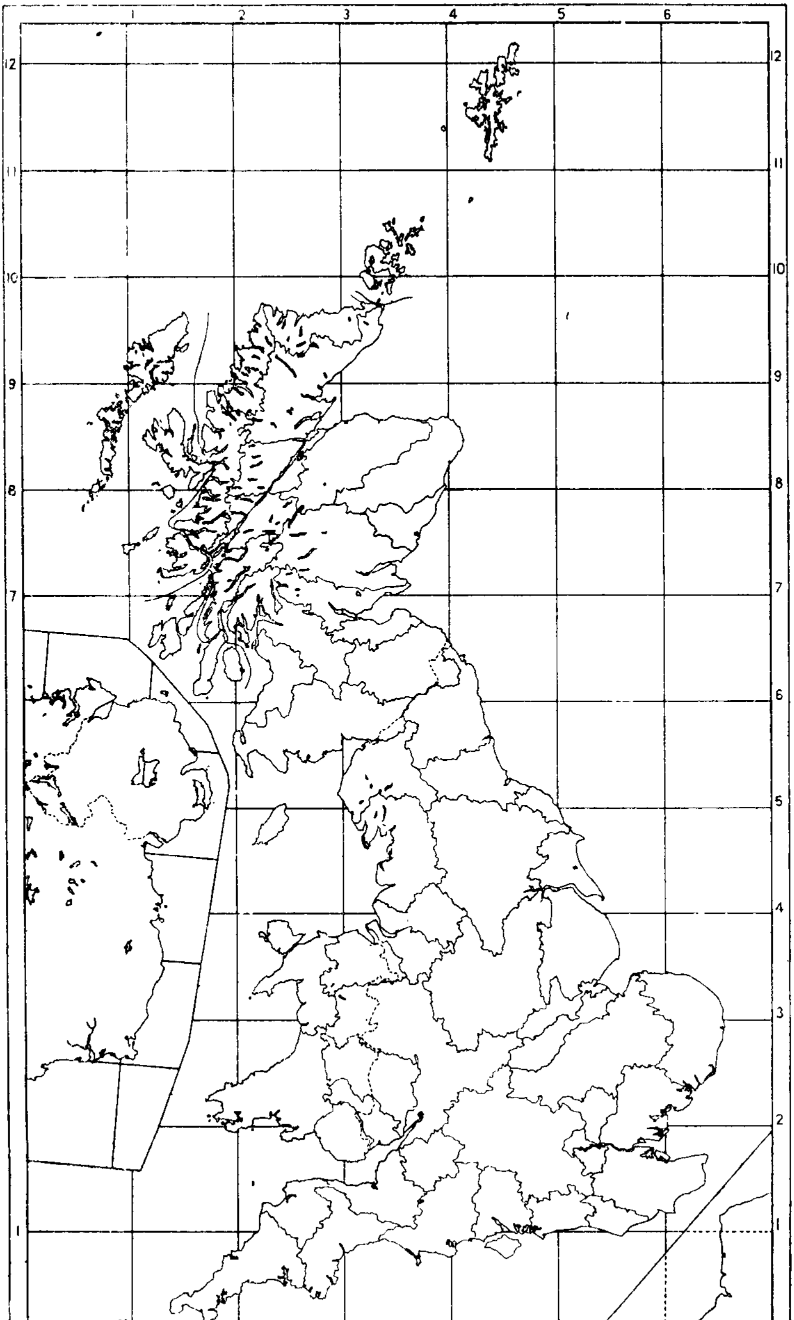

FIGURE I—RIVER CATCHMENT AREAS

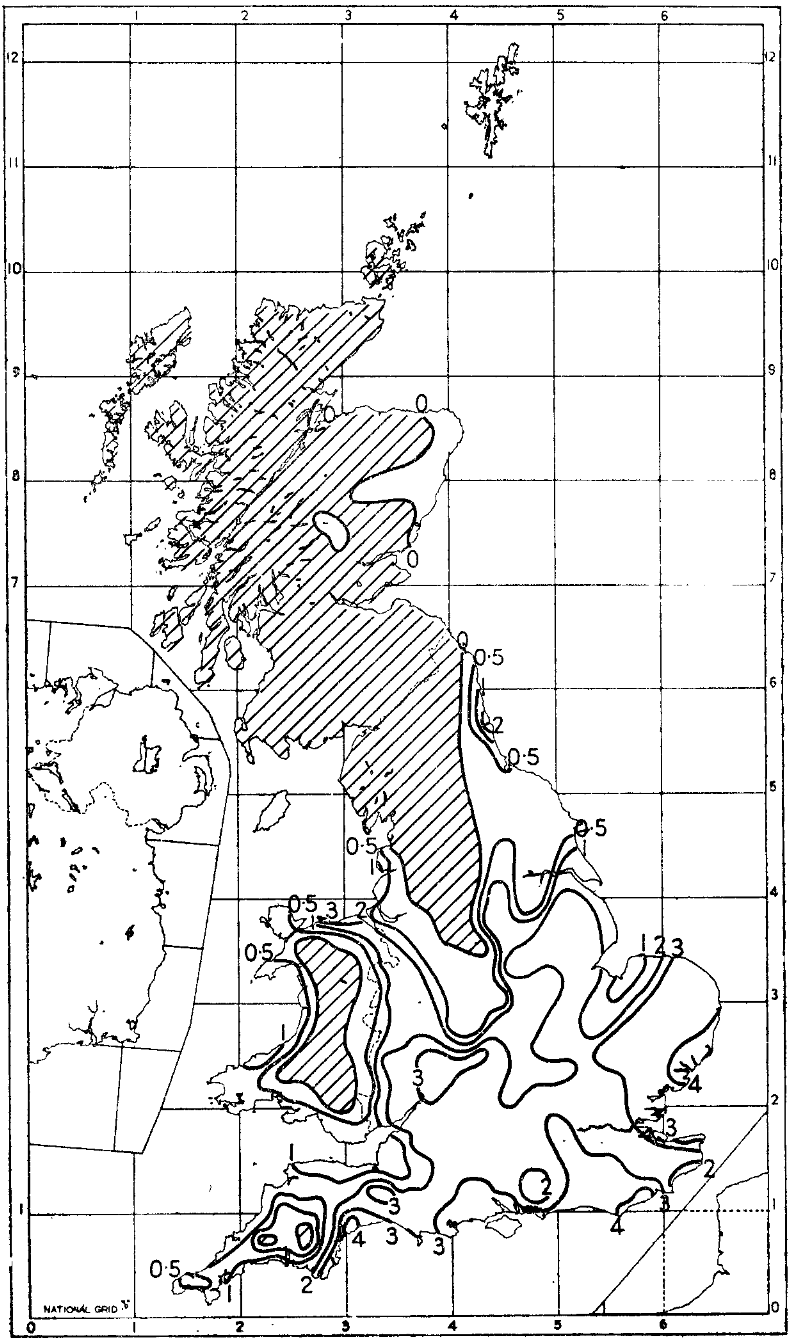

FIGURE 2—ESTIMATED SOIL MOISTURE DEFICITS AT 0900 ON 14 SEPTEMBER 1966

Areas with no soil moisture deficit are shaded, remaining areas divided by 0, 0·5, 1, 2, 3 and 4-inch lines.

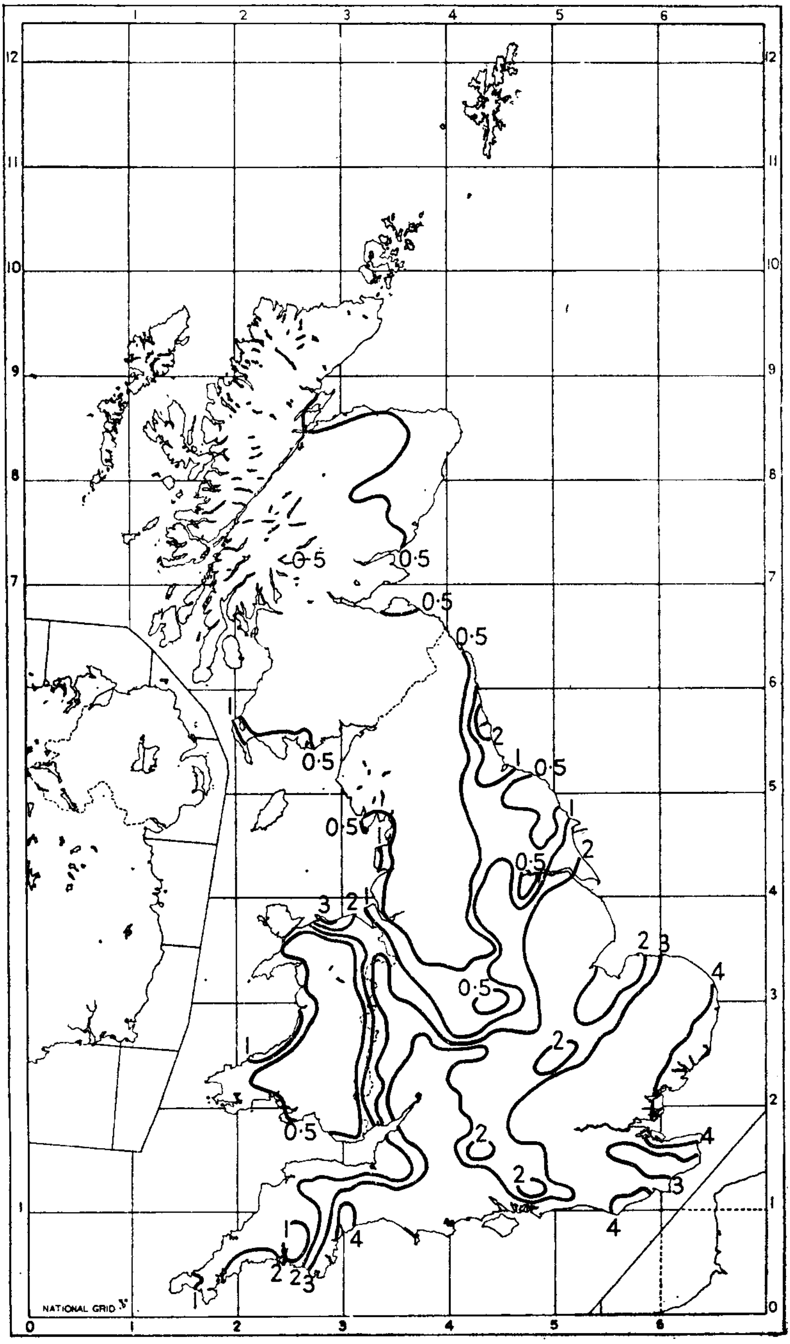

FIGURE 3—ESTIMATED SOIL MOISTURE DEFICITS AT 0900 ON 28 SEPTEMBER 1966
Areas are divided by 0, 0·5, 1, 2, 3 and 4-inch lines.

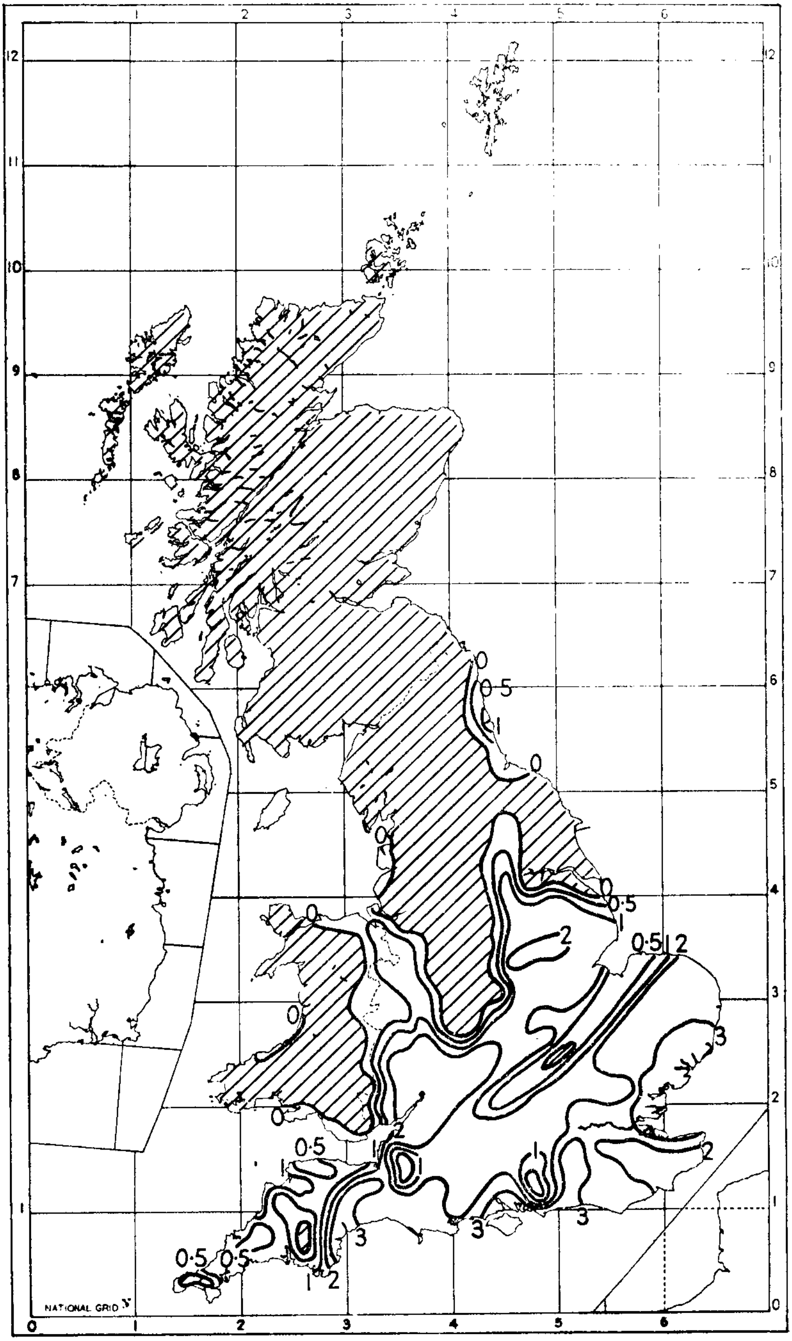

FIGURE 4—ESTIMATED SOIL MOISTURE DEFICITS AT 0900 ON 12 OCTOBER 1966

Areas with no soil moisture deficit are shaded, remaining areas divided by 0, 0·5, 1, 2, 3 and 4-inch lines.

estimates are used and the slope of the annual march of the evaporation curve is taken into account to give a more accurate estimate for the time of month.

In view of the wide scatter of the *Daily Weather Report* stations and the need to use average evaporation there is more uncertainty about the soil moisture deficit values obtained at mid-month than about the values at the end of the month. The errors are not accumulative; at the end of the month the soil moisture deficit is adjusted for observed values of rainfall and calculated evaporation. In drawing the maps subjective allowance is made for the variation of rainfall with altitude and other factors such as local thunderstorms. The thin solid lines on Figure 1 represent catchment boundaries of major river basins. Figures 2 to 4 illustrate a sequence of deficit maps for 14 September 1966 to 12 October 1966. The apparent deficit of ½ in on 28 September in areas which had had zero deficit on the previous maps is the result of a spell of dry weather lasting for about two weeks. Such deficits as these are transitory in highland Britain and are likely to be eliminated by the first major disturbance from the Atlantic.

The maps are accompanied, on issue, by a bulletin which discusses the weather of the preceding period in relation to soil moisture deficits, the changes which have taken place in soil moisture deficits since the preceding map and a comparison with similar dates in earlier years. A table gives estimates of mean soil moisture deficit over the major river basins and a statement of the amount by which the areal estimate has changed since the preceding bulletin.

Application of the data.—The maps and tabular statements are not intended as flood forecasts; the Meteorological Office cannot forecast floods. The deficit estimates are intended to aid the authorities in obtaining flood warnings and must be interpreted by river authorities and drainage engineers in the light of local knowledge about river systems and the factors governing river behaviour.

Simple forecasts of the date of restitution of soils to field capacity and resumption of appreciable run-off may be obtained by projecting average rainfall and run-off from the date of known soil moisture deficit.

More sophisticated forecasts may be made by using probability curves of rainfall distribution such as those prepared by Glasspoole[6] who obtained a family of curves showing the percentage of annual average rainfall occurring with a given probability in 1 to 16 consecutive months. With such data the likelihood of soil moisture deficits being made good on any date may be calculated with a given probability and the drainage engineer is provided with an objective assessment of the degree of urgency with which attention should be paid to flood warning systems. Also the water engineer may estimate, with given probability, the rate of depletion of reserves or forecast the date of restoration of reservoirs to full capacity. With such data the engineer may assess the risk of not imposing restrictions or of relaxing them.

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FREEZING DRIZZLE IN SOUTH-EAST ENGLAND ON 20 JANUARY 1966

By G. PARKER and A. A. HARRISON

Introduction.—Plenty of literature exists on icing of aircraft, but not nearly so much has been written about icing on the ground, where it affects a greater number of people. Glazed frost or 'black ice' is due to the freezing of water droplets on impact with the ground or other surfaces, but the far-reaching consequences of this comparatively rare phenomenon in this country are not always realized. On 20 January 1966, freezing drizzle coated the greater part of southern England with a thin skin of ice and the opportunity has been taken for investigating its effects in as many fields as possible, as the last comparable occurrence was as long ago as January 1940.

January had started in a stormy mood with rather changeable weather in most parts, but on the 9th winds backed south-east to east bringing air from Europe, and a cold spell ensued. By the 19th, much of England, except the south-west, and parts of Wales, Northern Ireland and Scotland were in the grip of snow and ice; even in the Channel Islands snow lay an inch deep. The sea was frozen in Pegwell Bay between Deal and Ramsgate and the air temperature at East Malling (Kent) had been as low as minus 16°C (4°F), the lowest there since 24 February 1947.

General cold spell.—A case of frost-bite was reported from the London docks where fires had to be lit under the superstructure of the hydraulic cranes to thaw them out. On the same day (19th) the Central Electricity Generating Board had supplied some 33 million kW of power, the greatest ever recorded. Frost had remained unbroken in most parts of south-east and central southern England since late on the 17th and at Little Rissington in the Cotswolds it had persisted for no less than 11 days. Earth temperatures too dropped below freezing, see Table I.

TABLE I—MINIMUM TEMPERATURES AT KEW, 18–21 JANUARY 1966

Date	Grass minimum	Surface	Below ground 2 in	4 in	8 in	12 in
			degrees Celsius			
18th	−7·6	−4·1	0·0	0·3	0·8	1·7
19th	−11·6	−6·5	−2·2	−0·6	0·5	1·6
20th	−4·7	−4·7	−1·7	−1·0	0·2	1·4
21st	0·3	−0·2	−0·1	−0·3	0·0	1·2

Weather conditions on 20 January.—During the 20th a small Atlantic depression broke through the barrier of high pressure and moved up the English Channel and temperatures started to recover, though very slowly at first.

By courtesy of Evening Argus, Brighton

PLATE I—BRIGHTON, 20 JANUARY 1966.

The salted road is seen to be preferable to what looks like a clear pavement, but is in fact covered by a thin skin of ice (see page 112).

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Photograph by R. K. Pilsbury

PLATE II—DISTRAIL AT ALTOCUMULUS LEVELS AT 0905 GMT ON 13 SEPTEMBER 1966
Contrail shows in clear air on the left.

However, conditions were to get worse before they got better. Rain, sleet* and snow moved across south-west England and the western entrance of the English Channel. On approaching central southern England the sleet and snow were accompanied by freezing drizzle; even snow grains and ice pellets were added to the repertoire as the precipitation belt moved inland, and yet a further item occurred in east Kent in the form of blowing snow. Along the south coast the precipitation turned to rain by late morning but elsewhere in the south-east the freezing rain and drizzle persisted well into the evening particularly north of the Thames and over high ground.

Road conditions on 20 January.—A combination of snow and hard frost prior to the 20th had alerted motorists to the hazards of slippery roads, so that the glazed ice on the 20th found them not entirely unprepared for precarious conditions. A good deal of salt had been put down and many of the major roads were just wet, but others were sheets of ice and applications of sand and grit were ineffective against the freezing drizzle. Not only were road surfaces difficult but windscreens were made opaque, being sandwiched between freezing rain on the outside and frozen breath on the inside. Many motorists reported that windscreen wipers and heaters were ineffective against this type of weather.

Weather log sheets of the Automobile Association included such statements as :

> '7 a.m. Freezing rain was falling over much of the Home Counties, conditions so bad that motorists were stopping on the "clearways" of the Kingston By-pass and M4 to clear windscreens of ice.'
>
> '12.25 p.m. A.A. Home Counties survey at noon showed that freezing rain had made road surfaces in Surrey, Sussex, Herts., Bucks., Berks. and Oxfordshire like glass, driving conditions most difficult.'
>
> '4 p.m. Conditions in places are about as bad as they could be with roads like skating rinks because of the freezing rain.'
>
> '5.45 p.m. Thousands of miles of road in 35 counties in the grip of ice and snow, worst conditions were in the south and south-east and Home Counties. This had been one of the worst motoring days this winter mainly because of freezing rain which had turned roads into "skid-pans" immediately it touched the ground. Breakdown services in the London area reported it had been one of the busiest days on record—1000 calls for help being answered in 24 hours.'

The Royal Automobile Club told a similar story.

Accident statistics: London.—In more quantative terms the statistics supplied by the Metropolitan Police show that the 245 accidents reported to the police were some 70 per cent above the daily average for the month and that 205 of these were on roads officially classified as 'slippery'.

The figure of 245 breaks down to 4 killed, 36 seriously hurt and 205 slightly hurt. The preponderance of 'slightly hurt' (205) in this accident analysis is noteworthy. A Metropolitan Police spokesman said that this may well have been because people were driving more slowly and generally taking more care but even so were encountering slight accidents.

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*Sleet is rain or drizzle and snow.

Accident statistics: United Kingdom.—The Ministry of Transport figures for the day in question (Figure 1) deal with the country as a whole and consider individual days of the week. On average, Saturday produces the greatest number of accidents but in this particular week, Thursday's total is comparable with Saturday's, and is made even more significant by the fact that this Thursday also had the lowest estimated vehicle mileage for a weekday since March 1965.

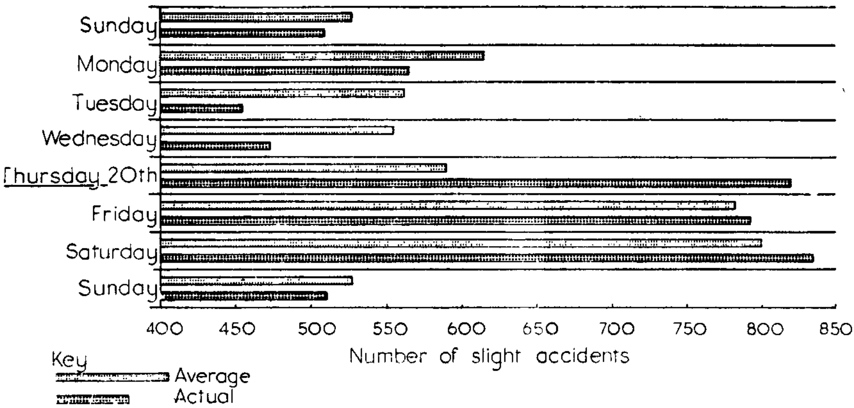

FIGURE 1—NUMBER OF SLIGHT ACCIDENTS IN GREAT BRITAIN RECORDED BY THE MINISTRY OF TRANSPORT DURING THE WEEK COMMENCING 16 JANUARY 1966 COMPARED WITH THE DAILY AVERAGE FOR THE MONTH

On the 20th the number of accidents was 131 per cent of average and the accident rate per estimated vehicle mile showed a similar percentage increase. The fact that Metropolitan Police figures (Figure 2) show an accident rate 70 per cent above average whereas the Ministry of Transport figures show only 30 per cent is not without significance since the Police dealt with an area wholly within that affected by the freezing rain and the Ministry of Transport covered all of Great Britain.

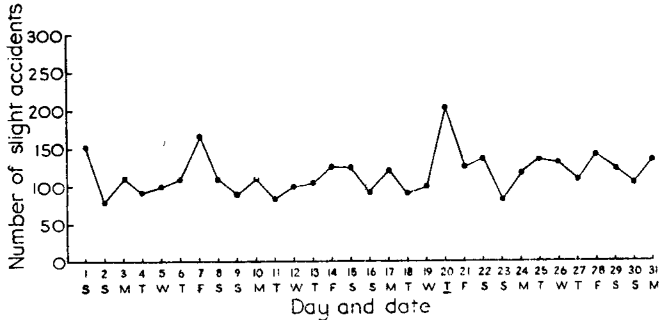

FIGURE 2—NUMBER OF SLIGHT ACCIDENTS IN THE METROPOLITAN POLICE AREA IN JANUARY 1966

News items on 20 January.—

(i) *Roads.*—Driving conditions on most roads could perhaps be described as 'exciting' and many reports have emphasized the fact that people did not know the road was slippery until they started sliding. An application of salt did not put an end to the slippery conditions in some places, indeed salt had to be applied several times in the Basingstoke–Guildford area where the solution of salt and ice was washed off the roads by :

(*a*) cars passing and splashing the solution to the side of the road, and

(*b*) the effect of the camber of the road.

The net effect was that after a time ice formed again on the road because of the freezing drizzle. Also, in this area, workmen found that the freezing drizzle formed a sheet of thin ice on their clothes.

One driver reported that he left his car stationary all day, and when he returned to it in the evening it was so effectively cocooned in ice that he had to wait until the next morning before he could even get into it !

In places drivers found conditions so difficult that they abandoned their cars on the road and sought the relative safety of buses which in the London area were generally delayed by 30 to 40 minutes; in Brighton and Hove the buses stopped altogether for a time during the morning. A number of places had burst water mains and as can be imagined this did not help matters.

(ii) *Docks.*—In the London docks work was delayed by ice-covered ropes and bridge mechanisms sticking, as well as by slippery areas on roads and railways.

(iii) *Railways.*—Railways to the south of the Thames were worst affected because:

(*a*) they mostly rely on current from the third rail which is more susceptible to icing than the overhead wires used elsewhere, and

(*b*) the freezing drizzle fell during the early morning when there were relatively few trains running, allowing a longer interval for the ice to collect.

The area most affected was between Guildford and Woking where as many as 97 'trippings' occurred between 10.30 and 11.30 a.m., all due to the freezing precipitation. (A tripping of a track circuit breaker occurs when arcing between the current rail and the pick-up shoe is severe and the current is automatically cut off. Normally the track circuit breaker can be reclosed in a matter of seconds, but if arcing occurs more than three times then serious delays develop.) It is not surprising that de-icing trains had to be run throughout the day. The trains were delayed further by freezing drizzle collecting on the drivers' windscreens and this had to be scraped off at each station. Another feature was that many platforms were ice covered and so people took twice as long to enter the trains.

North of the Thames the freezing drizzle occurred a little later when more traffic was passing along the lines; even so, de-icing trains had to be run along the electrified tracks during the day. The sections with overhead conductors were not affected as much as one might perhaps have expected. In general, freezing drizzle does not affect the overhead insulators, although if there is a good deal of atmospheric pollution both in the air and also deposited on the insulators then it will lead to a 'flash-over' or 'tripping'. There were three flash-overs, all occurring on the low-voltage section of the Eastern Region. It should be noted that a heavily polluted freezing fog causes far more trouble than freezing drizzle.

(iv) *Airlines.*—Airlines also had their difficulties; of the 368 services planned for operation that day by BEA (over the whole network), no fewer than 79 flights were cancelled and 49 suffered delays of more than one hour. Aircraft due to land at Wisley had to be diverted because of ice on the runways and at Gatwick and Heathrow, aircraft on the ground had to be de-iced the whole time.

(v) *Pedestrians.*—In general the coating of ice was very thin; even so, there were reports of $\frac{1}{8}$ to $\frac{1}{4}$ of an inch in places. Pathways and pavements in many areas did not have the benefit of sand, grit or salt and to the eye pavements looked innocent; yet in many parts there was the astonishing sight of people clinging to fences, walls, hedges, etc., trying to restore their balance. In the photograph in Brighton (see Plate I), the salted road is seen to be preferable to what looks like a clear pavement but which is, in fact, covered by a thin skin of ice. It was the pedestrian who suffered most and needless to say all hospitals in the area had more than their fair share of broken legs and wrists, etc.; there were no less than 212 cases at Croydon and 160 at Brighton. All hospitals in the south-east received a 'yellow' warning from the emergency bed service asking them to ban all but emergency admissions; the reason given was the large number of accidents caused by icy conditions and an expected increase in chest ailments. This was the first 'yellow' warning issued since January 1965.

(vi) *Trade.*—The trade of shops was also affected. A manager of a supermarket in the Home Counties said his trade was reduced by 40 per cent.

No doubt further instances could be found but it seems that few people in the area remained completely unaffected and it is fairly safe to say that had some warning not been given by the Meteorological Office matters would have been worse.

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THE SYNOPTIC CONDITIONS ATTENDING AN OCCURRENCE OF FREEZING DRIZZLE

By T. H. KIRK

The occurrence of freezing drizzle over southern England on 20 January 1966 was so widespread that it would appear desirable to place on record the attendant synoptic situation.

Over the British Isles at low levels there was an easterly stream of cold air from western Europe, while milder Atlantic air was crossing France from the Bay of Biscay. At 0000 GMT on 20 January a shallow depression was centred at the western end of the English Channel (Figure 1). Subsequent developments may be summed up in the statement that this small depression moved slowly eastwards with steady filling. Figure 2 shows the position at 1800 GMT. The essential feature was that although warmer air from the depression was over-running southern England at higher levels, there was in fact little penetration of warmer air at the surface and temperatures did not rise appreciably above freezing-point.

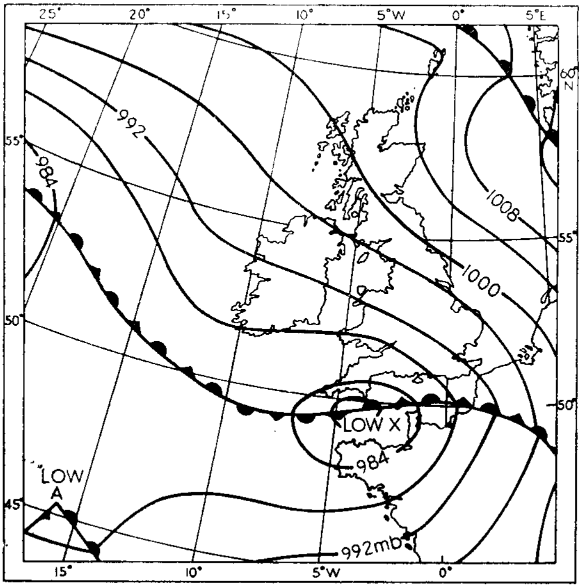

FIGURE 1—SURFACE CHART FOR 0600 GMT ON 20 JANUARY 1966

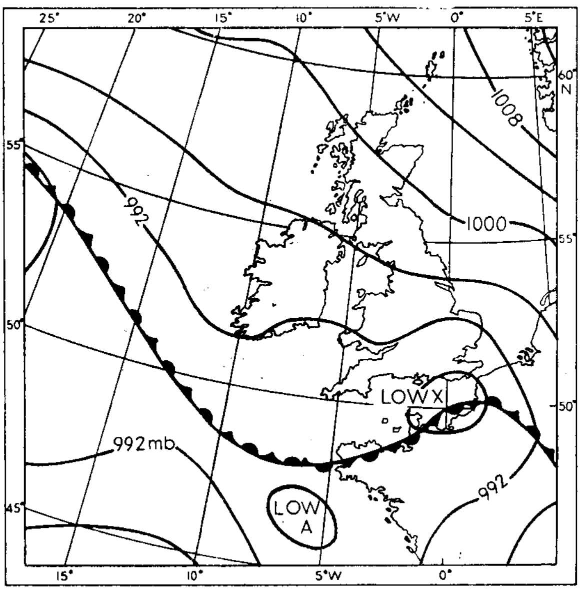

FIGURE 2—SURFACE CHART FOR 1800 GMT ON 20 JANUARY 1966

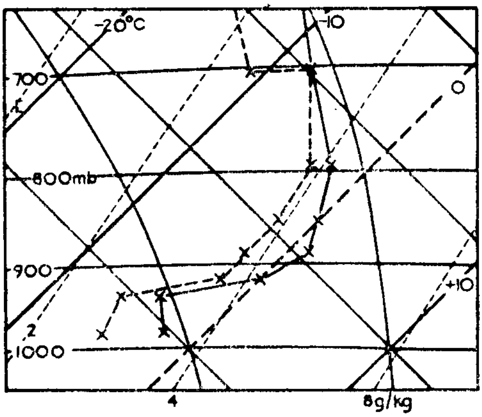

FIGURE 3—RADIOSONDE ASCENT, CRAWLEY, AT 1200 GMT ON 20 JANUARY 1966

——— Dry bulb - - - Dew-point

The warm air aloft can be seen on the ascent for Crawley shown in Figure 3. The 850 mb level is an appropriate one for showing to best advantage the northward movement of the warm air. Figure 4 shows the 850 mb chart for 0000 GMT on the 20th and Figure 5 shows the corresponding chart for 1200 GMT. It will be seen from these that the 0°C isotherm penetrated northwards to a position across southern England by 1200 GMT.

Little more can be deduced from the available evidence except that the drizzle was produced at freezing or near-freezing temperature and, falling through a shallow freezing layer, readily froze on contact with the ground or other surfaces.

One of the difficulties of this situation is that it does not appear to have very exceptional characteristics. Perhaps the most obvious feature was the influx of almost saturated air into southern England, replacing relatively dry air. Thus, at 0000 GMT on 20 January the air at Trappes (northern France) was saturated at 850 mb while Crawley had a dew-point depression of 14 degC. At 1200 GMT the dew-point depression at Crawley was 2 degC and at Hemsby it was 1 degC, both implying near saturation. This change of humidity was rapid whereas the rise in temperature was steady and relatively slow.

The weakening of the depression and its small size provided for a very gradual and general uplift of air, and would appear to have favoured the production of drizzle rather than rain. The lack of marked frontal activity and the movement of the depression along the frontal zone were both conducive to the exceptional features of the drizzle, namely its duration in time and the wide area of occurrence. If rain, rather than drizzle, had occurred, this might have led to sufficient warming to ensure that the occurrence of freezing precipitation would be severely limited in both space and time. It would seem therefore that the very weakness of the low was, in itself, a main factor in producing the occurrence of widespread and prolonged freezing drizzle.

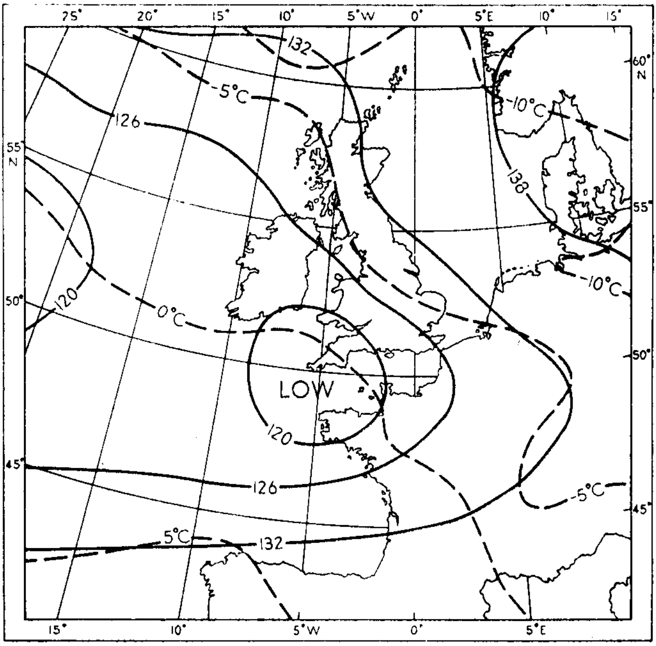

FIGURE 4—CHART FOR 850 MB LEVEL AT 0000 GMT ON 20 JANUARY 1966
Contours at intervals of 6 decametres. Isotherms at intervals of 5 degC.

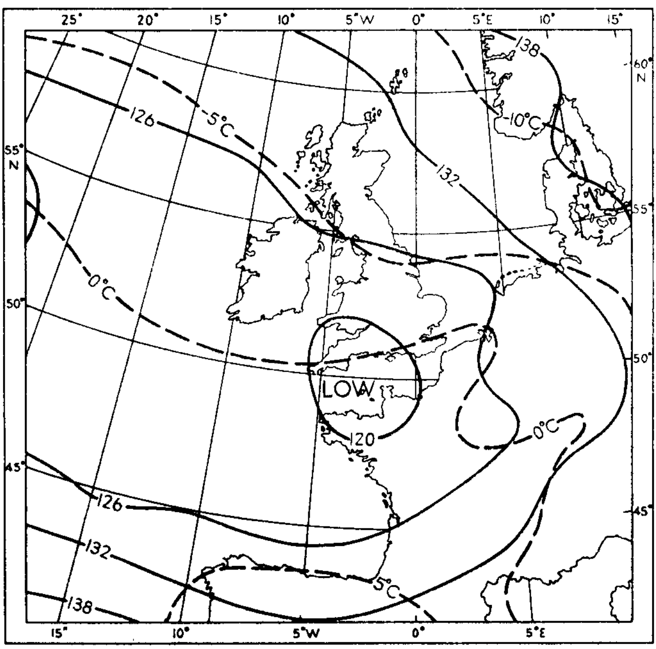

FIGURE 5—CHART FOR 850 MB LEVEL AT 1200 GMT ON 20 JANUARY 1966
Contours at intervals of 6 decametres. Isotherms at intervals of 5 degC.

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HONEY PRODUCTION AND SUMMER TEMPERATURES

By G. W. HURST

Bee keepers of experience are almost unanimous that there is not the profit there used to be in honey production, mainly because of falling honey production per colony. Statistics produced by the Honey Producers Association* show that in the period 1928 to 1949 an average for Great Britain of 50 lb or more of honey per colony was recorded on 10 occasions in the 22 years. From 1950 to 1966, only on 4 occasions out of the 17 was as much honey as this recorded. Occasions of 80 lb or more occurred in 1928, 1940 and 1947; 1947 was the year with the highest yield since 1928, when detailed records started. Honey production is well shown in Figure 1 which presents honey production for Great Britain as a whole as a 10-year running mean ending at the years indicated.

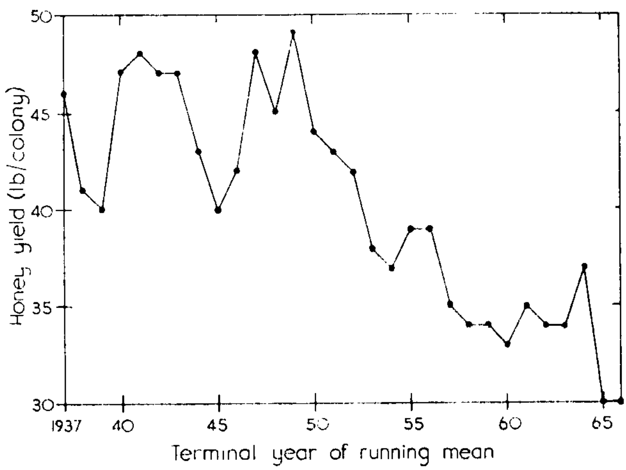
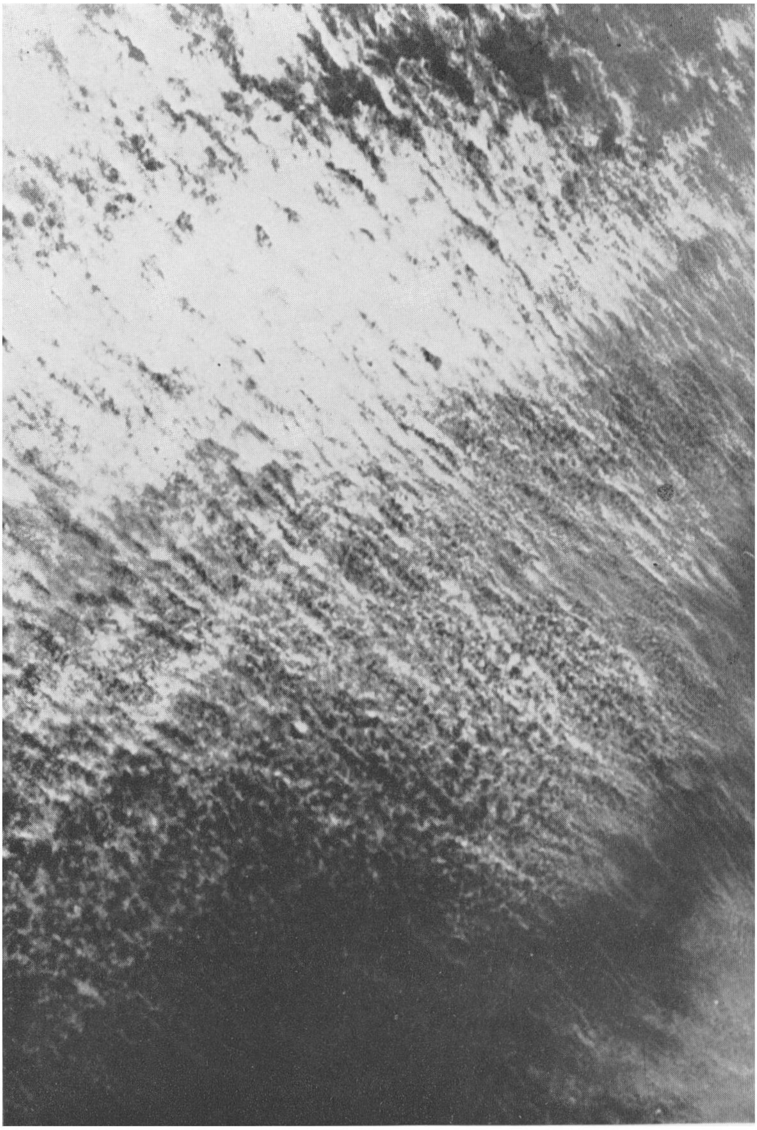


FIGURE 1—YIELD OF HONEY PER COLONY SHOWN AS 10-YEAR RUNNING MEANS

The factors which control the magnitude of a year's honey crop are complex, and some have no relationship with the weather. For the purpose of this investigation, such things as the effects of winter husbandry, changes in bee-keeping techniques, possible effects of insecticides, etc., are necessarily ignored. The weather can enter into consideration in many ways: in March and April, temperature and sunshine have their effect on the colony capability, and on the nectar-producing plants, and from May, or better June, onwards the nectar supply is available in different areas on different plants at different times. Particularly important are pleasant summer days with high temperatures, as these are the occasions when the bee (and particularly the continental bee) is really active; vital to a high honey yield is the right weather at the right time in summer. Clearly, one can hardly expect to find a particularly close relationship between average or accumulative meteorological parameters and production, but one might look for a general relationship between 'good' summer weather and honey production. Bee-keeping experience shows that



Photograph by R. K. Pilsbury

PLATE III—CIRROCUMULUS LACUNOSUS

To face page 117

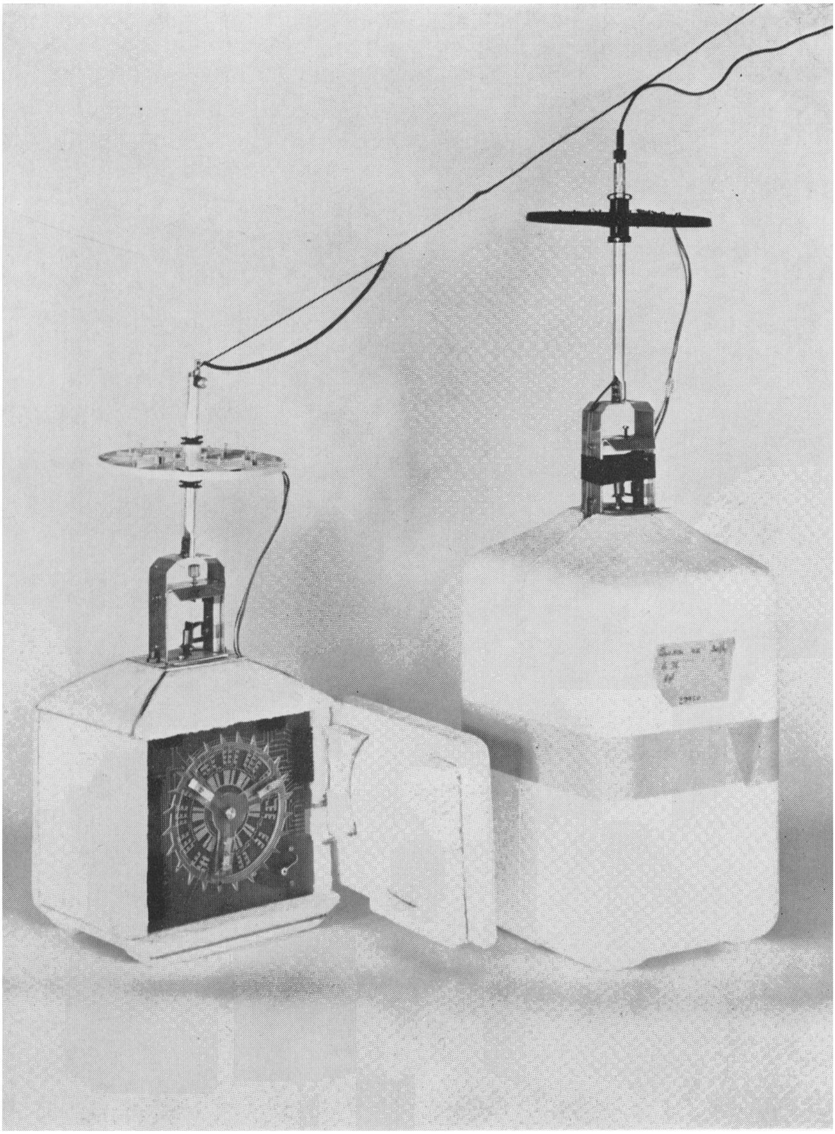


PLATE IV—THE PROTOTYPE (ON THE RIGHT), MK 3, AND PRE-PRODUCTION MODEL, MK 3b, OF A NEW RADIOSONDE

See page 127.

the sort of weather associated with a high level of honey-bee activity is that of a fine warm summer, with good sunny days preceded by mist or dew-fall. This type of detail is obviously difficult to pick up in analysis, so the problem has been simplified into a consideration of temperature and sunshine (ideally radiation should be examined).

Departures from the sunshine and temperature monthly averages over Great Britain (standard period 1921–50) for the months from March to September were first plotted as dot diagrams against weight of honey per colony, and in some instances the scatter was such that the relationship between the two was clearly rather poor. In both July and August, however, there was a definite suggestion of a relationship, particularly between departures from summeı average temperatures and honey yíeld. This is well borne

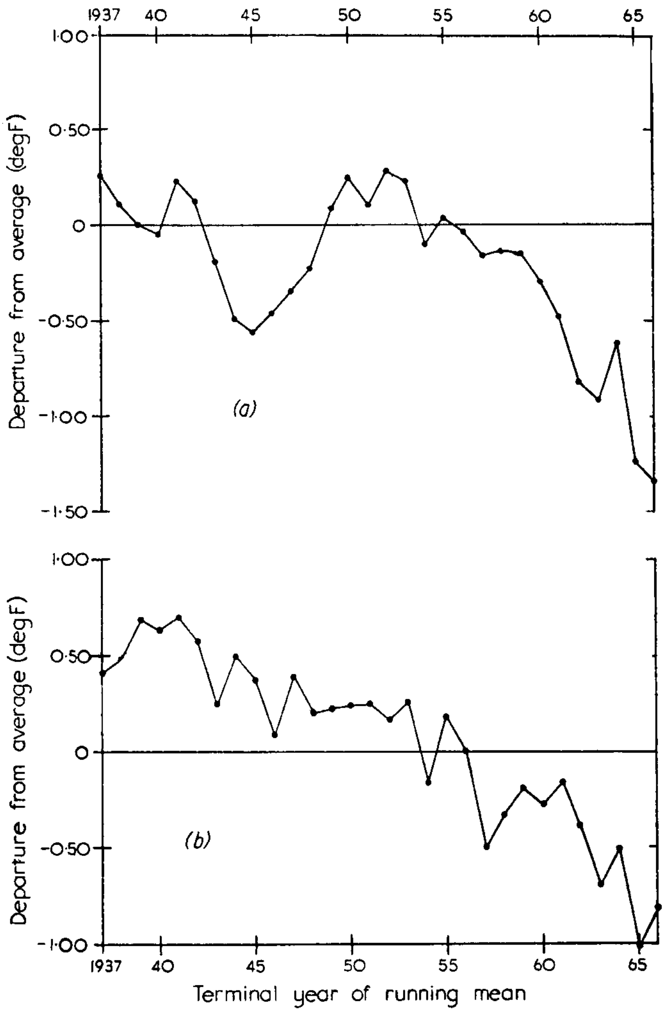


FIGURE 2—DEPARTURE FROM AVERAGE TEMPERATURE IN GREAT BRITAIN IN JULY AND AUGUST SHOWN AS 10-YEAR RUNNING MEANS

(*a*) July (*b*) August

out by Figures 2(*a*) and (*b*), in which the July and August 10-year running mean temperatures are shown ; the agreement (especially that of August) with the annual honey yield per colony shown in Figure 1 is very clear. A correlation of + 0·59 (significant on the 0·1 per cent level) has been established between the yearly production of honey and the departure from average of the August temperature. The correlation between honey yield and the 10-year running means was naturally higher because of the measure of smoothing introduced by the running means, and reached + 0·85 for August and + 0·82 for July and August temperatures combined.

The correlation between the yield and the temperatures of July and August is not unexpected as in one or other of these months the gathering of honey is normally at its greatest. Moderate relationship was seen to exist between June temperatures and honey yield; however, this was also to be expected as much honey is collected in the second half of June in some places in southern districts.

Outstandingly good years for production with 75 lb or more per colony were 1928, 1935, 1940, 1947 and 1955 and bad years with less than 15 lb a colony were 1936, 1954, 1958 and 1965. Earlier reputedly good years before detailed records were maintained were 1906, 1908, 1911 (said to be the best of all time), 1921 and 1925, and bad years were 1907, 1917, 1922 and 1927. July and August departures from average of sunshine and temperature are shown in Table I(*a*) for the good years and in Table I(*b*) for the bad years.

TABLE I—DEPARTURE FROM AVERAGE TEMPERATURE AND SUNSHINE IN GREAT BRITAIN IN JULY AND AUGUST

(*a*) Years of high honey yield

Year	July Temperature *degF*	July Sunshine *hours*	August Temperature *degF*	August Sunshine *hours*
1906*	+ 0·9	+ 54	+ 3·0	+ 55
1908*	+ 0·1	− 8	− 1·8	+ 22
1911*	+ 1.0	+ 12	+ 4·4	+ 139
1921	+ 1·4	+ 56	− 0·3	− 15
1925	+ 1·1	+ 10	0·0	− 18
1928	− 0·3	+ 32	− 0·6	+ 3
1935	+ 1·5	+ 53	+ 1·4	+ 13
1940	− 1·9	− 8	− 0·5	+ 7
1947	+ 0·9	− 10	+ 4·4	+ 90
1955	+ 2·2	+ 83	+ 3·6	+ 27
Average	+ 0·7	+ 27	+ 1·4	+ 32

(*b*) Years of low honey yield

Year	July Temperature *degF*	July Sunshine *hours*	August Temperature *degF*	August Sunshine *hours*
1907*	− 3·5	− 2	− 1·7	− 3
1917*	0·0	+ 15	− 0·5	− 15
1922	− 3·8	− 19	− 3·2	− 30
1927	− 0·8	− 29	+ 0·1	− 1
1936	− 1·1	− 30	+ 0·7	+ 7
1954	− 3·1	− 38	− 2·3	− 39
1958	− 1·1	+ 1	0·0	− 37
1965	− 3·9	− 44	− 1·5	+ 3
Average	− 2·2	− 18	− 1·1	− 14

*Departures from average London temperatures and sunshine;[1] in remaining years the departures are from averages for Great Britain 1921–50.[2]

Of the 10 good years, half fit well into the pattern of a warm sunny high summer, and in 1921 there were obviously long sunny spells in July. In 1908, June was rather warm and very sunny, and August was sunny if a little cool. June 1925 was rather warm and sunny, and 1928 was quite sunny in July if not particularly warm. In 1940, June was very warm and sunny.

In none of the 8 bad years was the mean temperature or sunshine of the two months above average, and in at least 5, high summer was clearly cool and sunless.

It is thought that this measure of agreement between the weather and yield is quite close, bearing in mind both the very broad yardstick used and the host of other factors which may be involved. The point has already been made that the right weather at the right time is important; for example, if a short period of only 7 to 10 days of an average August is warm and sunny, honey yield may still be above average if the good weather coincides with other favourable factors such as high level of bee activity or increased availability of nectar.

The choice of 75 lb and 15 lb as boundaries marking good or bad honey production years is of course arbitrary, and years which just failed to be categorized as good were 1934, 1949 and 1959, and years which likewise just failed to be classified as bad were 1930, 1948, 1953 and 1963. The inclusion of these years would have made little difference to the averages shown in Tables I(*a*) and (*b*); the July average including the three additional near misses for good years would have been + 1·0 degF and + 28 hours, and the August average + 1·4 degF and + 29 hours. Inclusion of the four bad years would have resulted in averages in Table I(*b*) of – 1·9 degF and – 13 hours in July, and – 1·0 degF and – 14 hours in August.

A final approach to finding a meteorological basis for the gradual fall in honey production was made by comparing actual temperatures with an assumed minimum threshold temperature for bee activity. For continental bees, 60°F can probably be regarded as a suitable threshold temperature (though again it is underlined that this kind of concept must be a gross over-simplification). Accumulated temperatures, totalled for the four periods of 10-year running means are shown in Table II. The approximate method of using monthly averages described by Shellard[2] has been employed. For this table, only England and Wales have been taken into account, because few, if any, continental bees are kept in Scotland.

TABLE II—AVERAGE ACCUMULATED TEMPERATURES IN DEGREE DAYS ABOVE 60°F FOR ENGLAND AND WALES FOR 10-YEAR RUNNING MEANS

Period	June	July	Aug.	Sept.	July and August	Year	Average honey yield
			degree	*days*			*lb per colony*
1928–37	43	94	83	63	177	283	46
1937–46	44	76	75	29	151	224	42
1947–56	43	87	72	31	159	233	39
1957–66	47	59	59	31	118	196	30

The agreement between temperature accumulation and honey yield is reasonably good—there is a fall from the second to the third period of honey yield, which does not quite agree with the slight recovery of average temperatures, but the overall pattern is recognizable.

A threshold temperature of 60°F is probably too high by about 10 degF for British bees, and similar calculations were made for accumulations of temperature above 50°F. These gave a similar pattern of falling temperatures over the 39 years, but naturally the amount of fall in degree-day totals, expressed as a proportion of the yearly sums, is less than the proportional falls obtained from Table II.

A significant point illustrated by Figure 2(*b*) is that there has been a fall in the average August temperature since 1930 of 1·0 – 1·5 degF. Even if no further fall of temperature occurs in August it is possible that it might be advisable to adopt the same husbandry methods in the south as those used rather further north; the average difference in temperature in August between say the Tees area and the Thames Valley is, after all, only 2·5 – 3·0 degF.

It is obvious that knowledge of future summer weather would be of the greatest importance to the bee-keeping industry—but the difficulty of providing this information is even more obvious. Some things can be said however. It is the view of many meteorologists engaged on the problem that the period around the 1930's and 1940's was one with exceptionally high summer temperatures, and Lamb[3] has produced graphs in this connexion hinting at the existence of a long-term cycle. Three possibilities for the future are (i) that the limit of fall of temperature has been reached, and that we are in a trough, (ii) that further cooling will take place for some years, followed by a recovery, or (iii) that the present value will continue for several years with oscillations above and below the present value.

Acknowledgements.—The author is indebted to Mr B. Ardill, of the Honey Producers Association, and to Mr B. A. Cooper of the National Agricultural Advisory Service, East Midlands, for advice and comments.

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2. SHELLARD, H. C.; Monthly averages of accumulated temperatures above and below various base temperatures for stations in Great Britain and Northern Ireland, 1921–50. *Br. clim. Brch Memor., London, No.* 5, 1956 (available in the Meteorological Office Library).
3. LAMB, H. H.; Climate in the 1960's. Changes in the world's wind circulation reflected in prevailing temperatures, rainfall patterns and the levels of the African Lakes. *Geogrl Jnl, London,* **132,** 1966, p. 183.

REVIEWS

Frostschutz im Pflanzenbau, by F. Schnelle. Band 1: *Die meteorologischen und biologischen Grundlagen der Frostschadensverhütung.* Size 9¾ in × 7¼ in, *illus.*, pp. viii + 488. Band 2: *Die Praxis der Frostschadensverhütung.* Size 9¾ in × 7¼ in, *illus.*, pp. viii + 604. BLV Verlagsgesellschaft, 8 München 13, Lothstrasse 29, 1963, 1965. Price: Each DM 140.

Certain publications stand out as landmarks in the study of a particular subject. One of these is the book published in 1940 by the German authors Kessler and Kaempfert on the prevention of frost damage. Since then there has been frequent frost damage in Europe, though probably the 1930's still remain the worst period in this country. Also, many new papers have been published on frost, so that the appearance of another comprehensive work on this topic is welcome. This comprises two volumes produced under the direction of Dr Fritz Schnelle, until recently head of the division of agricultural meteorology in the German service. He has written a number of the chapters and others have been contributed by Dr Aichele, Hans Burkhardt and Maximilian Schneider, all of the German agrometeorological service, and by Dr Baumgartner of the Meteorological Institute of the Bavarian Forestry Research Establishment in Munich. Each of these collaborators has his own field of interest in the subject and to some extent their chapters are based on their own experience.

The first volume deals with the meteorological and biological bases for the prevention of frost damage and the second with the practical aspects. The treatment throughout is comprehensive, a result of a most thorough search of the literature. Wherever appropriate the physical principles are described, often with the aid of diagrams, and every attempt is made to impart understanding as well as information. As a result, Volume 1 in particular may be used either as a textbook or as a reference book; Volume 2 is more likely to be used for reference as it deals largely with methods of preventing frost damage and the various types of apparatus which may be used for prevention.

It is not possible to give more than a hint of the wealth of information in these books and perhaps as good a way as any is to say a little on a few points of particular interest. For example, one may pick on sections where the information is probably different from what would have appeared in a similar work published in this country. The portion of Chapter 1 which deals with the sub-division and nomenclature of frost uses a number of unfamiliar terms, including 'Austauschfrost', which is differentiated from radiation frost by the fact that the katabatic downflow leads to some mixing of the air and therefore to some cooling of the upper layers; this implies that strictly a radiation frost can occur only on level land and contrasts with the generally understood meaning in this country, viz. a frost which occurs on a radiation night. When speaking of winter frosts, the term 'Barfrost' is used to denote frosts which occur when there is no snow cover; 'Wechselfrost' is used to define periods of alternating frosts when, for a period of several days, the temperature falls below 0°C by night and rises above it by day. The German agrometeorological service differs from the British in the emphasis which it places on phenology, and it must be conceded that frost damage is a function of phenology as well as of temperature. Table 22 gives a phenological calendar for the period of frost damage, using wild plants (including forest trees), cultivated crops and fruit. This refers to the uplands of southern Germany, and the earliest entry is for cherry blossom with a mean date of 23 April; the latest entry is for the end of apple blossom (Landsberg Renette) on 22 May.

Chapter 3 deals with the heat exchange of soils and plants and there is at least the hint of an answer to most questions on these topics. Many of the tables and diagrams are valuable in practice, for instance the text-table on p. 121 giving approximate values for the nocturnal cooling of different surfaces. But, as with all compilations, the material needs to be used with caution, and the table and Figure 32 seem to give somewhat contradictory results for wet sand and dry sand. Section 5 of Chapter 3 is concerned with the heat exchange which results from the change of state of water and a number of the facts given here are of obvious importance in the practice of frost prevention (by sprinkling). For example, according to Niemann the gaps between successive water-sprinklings must not exceed 3 minutes and this is supported by Figure 45 (after von Pogrell) which shows the marked increase in the temperature variation of tomato leaves as the period between successive sprinklings is increased. Also, Figure 43, after Nakagawa and Tsuboi, enables an estimate to be made of the minimum rate of application (mm/h) necessary to prevent frost damage, in relation to wind speed and air temperature.

Chapter 4 deals with the influence of the land on the stratification and movement of nocturnal cold air and this is treated in what may be called the classical manner, with the normal distinction between donor and recipient areas for cold air. Again, the collection of so much information is of prime importance and it is almost certain that anybody who reads this chapter will find some facts of which he was unaware—or had forgotten; for example, the possibility of a quasi-periodic variation of temperature resulting from a downslope movement of cold air 'drops'. Figure 84 reminds us that the upper limits of the nocturnal inversion on radiation nights depend as much on valley form as on meteorological factors and that it may be 100 m higher in a narrow valley than in a broad one, and in a broad one 80 m higher than in the neighbouring plain. There are clearly different standards of comparison between England and Germany, as Figure 85 and the text below define 'danger zone II' as having frost damage once or twice a decade, but sometimes not at all. For this zone it is stated that there are often large orchards, but that such sites should be avoided for commercial horticulture. This is certainly not valid for this country as the reviewer knows of one farmer who is prepared to plant blackcurrants provided that serious damage occurs only once in 2 or 3 years. Clearly, when discussing frost risk in relation to horticulture, all possible uses for the land must be considered, and an economic assessment made for each of these possibilities. One method of frost prevention that has been suggested in this country is the flooding of the valley bottoms where this is practicable. It has always been doubtful whether this is likely to be efficient and it is therefore interesting to read in Section 3 of Chapter 4 of the relatively slight effect which may be expected. For example, along the river Elbe, with an on-shore wind the effect was only 0·1–0·3 degC at a distance of 150 m, though no doubt it would be greater if the air were moving along the direction of the river and therefore the cold air remained longer over the water.

The main object of frost investigations is usually the assessment of the relative risk in different areas, something which can best be done by mapping. Chapter 5 deals with this topic which is amplified in Appendix 1 by details of the methods used in the German Weather Service. Their methods differ somewhat from ours, particularly in the fact that they use only measurements made on radiation nights, a practice which has much to commend it. Of the many maps, Figure 106 shows strikingly how irregular is the progression of frost damage. Five categories of damage are used from 'undamaged' (vines) to 'total loss', and there are regions on this map where these two are shown in juxtaposition.

Chapter 7 deals with the question of forecasting frost and Table 90 (covering 11 pages) summarizes all the methods known to the author. There is some overlap between the methods, but of the 43 cited only 3 are recommended, 11 are not recommended, 14 need further verification, 11 are unverified (or the verification is unknown), 2 are of only limited use and 2 are of no use. The last three chapters of this volume emphasize the biological aspects of frost under the general title 'The effect of frost on plants'.

Volume 2 is entitled 'The prevention of frost damage in practice'. The first part deals with the long-term aspects of preventing frost damage, the second with active measures against frost danger, and the third with the organization of frost warning and defence. Together these give a comprehensive account of all possible measures which may be taken to prevent or reduce frost damage—from biological measures to purely physical ones such as heating, using the latent heat of water sprinkled over the crop, and mechanical means of bringing the warm air aloft down to ground level. This is essentially a practical book to be used for reference.

There are two extensive bibliographies collated by Maximilian Schneider; that in Volume 1 has some 800 entries which have been referred to in the text, and that in Volume 2 contains some 3200 items although it is restricted mainly to the year 1940 onwards. There are over 300 diagrams and photographs, all excellently produced. These two volumes must be strongly recommended to anybody with an interest in frost and frost prevention, and even those who have only a slight acquaintance with the German language will be able to derive much from the tables and diagrams.

W. H. HOGG

The use of satellite pictures in weather analysis and forecasting, WMO Tech. Note No. 75, by R. K. Anderson, E. W. Ferguson and V. J. Oliver. 11 in × 8½ in, pp. xiv + 184, *illus.*, Secretariat of the World Meteorological Organization, Geneva, 1966. Price: Sw.F.24.

ESSA II, the first United States Weather Bureau operational satellite, was launched in February 1966, and since then over 86,000 pictures have been transmitted from the satellite by the automatic picture transmission (APT) facility and a further series of APT pictures has been received from the experimental NIMBUS satellite. This data, widely distributed throughout the world, represents a considerable library of information to which this *Technical Note* provides a very valuable index. The *Note* summarizes what is currently known about the relationships of satellite-viewed cloud formations to atmospheric motions and temperature structure, and shows how the data can be applied to daily meteorological analysis. The use of satellite pictures in forecasting, implied by the title as part of the subject of the *Note*, really comes down to the improvement in forecasting which would be expected from improved analysis alone. Satellite pictures are, however, part of the data on which a better understanding of the behaviour of the atmosphere can be based, eventually leading to improvements in forecasting beyond the immediate effects of more accurate analysis. The selection of 113 satellite pictures, presented and discussed in this *Note*, covers most of the major features of cloud organization and convincingly demonstrates the importance of this new source of data to the analyst. The format of the *Note* could be improved by bringing text and pictures together, thus eliminating the need for continual cross-reference between successive paragraphs of the continuous text and the separate collection of photographs. There is an error on p. 30 where the reference to Figure 46 should be to Figure 47. This is a *Technical Note* which should be on the book list of every meteorologist and is essential reading for those engaged in the interpretation of APT pictures.

I. J. W. POTHECARY

Agricultural physics, by C. W. Rose. 8 in × $5\frac{1}{4}$ in, pp. xvi + 226, *illus.*, Pergamon Press, Headington Hill Hall, Oxford, 1966. Price: 21*s.*

Hitherto there has been no textbook to help teachers and students to understand the ideas behind research papers and review articles on the microclimatology and soil physics of plant growth. Now there is, and Dr Rose is uniquely qualified to produce it. He taught the subject as a university lecturer in Uganda, and now he does it, in full-time research in Australia; the accumulated experience has produced a very good book. In welcome detail, Dr Rose first sets out the physics of the aerial environment of plants—a good refresher course for established meteorologists and likely to be very helpful for trainees—and then moves on to the rather more difficult physics of the soil. The very thorough treatment, supported by many excellent teaching diagrams, too often ends at an equation that is not brought to life by a field example; students will not be helped by: '*A*'s analysis leads to an algebraic equation, which was compared by *B* with others in use in field studies'.

Unfortunately, the leisurely progress permits mannerisms in writing to become obvious. Too much happens 'under conditions' (plants grow under soil conditions; I work under British climatic conditions), and 'high' and 'low' are very much overworked adjectives. There are correct statements that are either confusing or unhelpful, e.g. radiant emittance is defined as the energy in a 'wave-length interval 1 cm wide centred on the wave-length concerned', and a van der Waal's force is defined as that which 'gives rise to the constant *a*' in van der Waal's equation (not given). Discussion of soil structure is almost free from physics (not the fault of Dr Rose—it's the state of the subject), but like too many others his descriptive account is marred by use of 'good' and 'bad'. In the account of the lower limit of availability of water he dismisses in rather offhand manner a thermodynamic concept that revolutionized thinking about plant/water relationships some 30 years ago; but this bit of thermodynamics is more frequently quoted than read, and more frequently read than understood.

There are many references given, suggesting that Dr Rose wants his book to be treated as a research monograph. It is not, nor do we want it to be anything of the kind. When a second edition is called for—as it surely will be—changes should make it even more of a teaching book. There are many 'sources' of good research reviews, but few sources of good teaching material, and in the borderlands of meteorology, pedology, and botany there are some very strong 'sinks' for such a book as Dr Rose has written.

H. L. PENMAN

Physique de l'atmosphère, Tome III, by E. Vassy. $9\frac{1}{2}$ in × 6 in, pp. viii + 287, *illus.*, Gauthier-Villars, 55, Quai des Grands-Augustins, Paris VI^e, 1966. Price: 45F.

As stated in the introduction, the object of this book, which is the third volume of the series 'Physique de l'Atmosphère' is to describe as completely as possible the phenomena of absorption, diffusion and polarization of radiation in the atmosphere to students who have only a general knowledge of physics. The author, who has carried out research in radiation for many years, has been successful in achieving this object.

The title of the first chapter 'Absorption and diffusion of visible radiation' is a little misleading, for it is concerned also with radiation in the infra-red and ultra-violet. After stating Lambert's law the author discusses the methods of measuring absorption both by the whole atmosphere and in the lower layers. The results of the measurements and their interpretation is fully discussed, and as clearly as is possible with such a complex subject.

Chapter II is concerned with the intensity of solar radiation, visible and infra-red, at the earth's surface, and the measurement of global and diffuse radiation and the effect of cloud. A short third chapter describes the mainly classical work on the polarization of diffuse solar radiation, and a short fifth chapter deals with coronae.

Chapter IV will be of more special interest to conventional meteorologists, as it deals very thoroughly with measurements of visibility. The difference between the definition of visibility at night and in daylight is carefully dealt with, and the question of visual threshold is also very well explained and dealt with in detail.

In Chapter VI there is a jump in the scale by several orders of magnitude, as this chapter discusses absorption and diffusion in the atmosphere of radio waves of the order of centimetre wavelengths. Chapter VII discusses the absorption and diffusion of radio waves in the ionosphere while Chapter VIII deals with the diffusion of radio waves due to atmospheric turbulence.

The final chapter (IX) discusses the composition and thermal structures of the atmosphere as revealed by measurements of absorption, diffusion and spectral structure of radiation with a short note on the meteorological application of radar.

This book can be adversely criticized on two counts. Firstly on the virtual absence of references. In the whole book there are only 16 references to other work (of which 7 are to other Gauthier-Villars's publications). It is true that some books are overloaded with references, and it can be argued that if the work is well described there is no need to refer the reader to the original papers, but it is annoying to read 'Chapman a donné au point de vue mathématique la solution correcte et complète du problème' without knowing who Chapman is and where he published his correct solution. As far as the reader is concerned the sentence may as well have been omitted. It is to be hoped that in a subsequent edition a short but adequate list of references to the work described in each chapter will be given.

Secondly little effort appears to have been made to make the figures as clear as possible to the reader. Most of them appear to have been copied from the original with the result that, in the first chapter, wavelengths are sometimes expressed in ångströms and sometimes in micrometres, while wavelength increases to the right in some figures but decreases in others. Some of the figures have no captions other than, for example, 'Résultats de A. Vassy' and one has to read the text to find out what the figure is about. In some cases the units are not given in the figure, and sometimes not even in the text; in Figure IV.1 the expression for the ordinate contains terms which are not explained. It sometimes happens that an author as pre-eminent as Professor Vassy overlooks the fact that what is obvious to him may not be obvious to the student. After all, textbooks are written for the uninitiated, not the initiated. There are a number of misprints and a thorough revision of the figures is necessary.

In spite of this criticism the contents of this book give an interesting and useful introduction to the subject. A wide field is covered and the book is written with the lucidity in which French scientists are expert. The French itself is so simple and straightforward that there are no translation problems.

R. A. HAMILTON

Know the weather by C. E. Wallington and D. E. Pedgley. 8 in × 5¼ in, pp. 48, *illus.*, Educational Products Ltd, 17 Denbigh Street, London, SW1, in collaboration with the Royal Meteorological Society, 1966. Price: 3*s*. 6*d*., (bound) 7*s*. 6*d*.

This small book is an elementary introduction to the subject and has been published in collaboration with the Royal Meteorological Society. The various aspects of meteorology (atmospheric pressure, wind, cloud, precipitation, fronts, etc.) are described and explained, and there is a section on measuring the weather elements, with photographs of the instruments used. The latest developments in weather forecasting, including the use of radar, meteorological satellites and computers, and long-range weather forecasting, are briefly considered. Finally there are hints on 'reading the weather signs' and some information on how to obtain weather forecasts when required.

The authors have aimed to arouse and retain the interest of the reader. Much careful thought and hard work have gone into the numerous diagrams and maps which play a large part in the explanations. The combinations of diagram and photograph, as in the case of orographic stratus, are particularly effective.

'Know the weather' is good value for the money and should appeal to many people who, thanks to radio and television, have gained a superficial knowledge of meteorological terms, but know little of the physical factors which control the weather. It should prove useful also in schools, where it could be used as a supplementary book in the geography and general science courses.

F. R. DOBSON

The restless atmosphere, by F. K. Hare. 8¼ in × 5¼ in, pp. 191, *illus.*, Hutchinson and Co. Ltd, 178–202 Gt Portland Street, London W1, 1965 Price: 11*s* 6*d*.

'The restless atmosphere' first appeared in 1953 and has now been reissued in a fourth edition, completely reset on larger pages and with clear type, and is available as an attractively produced paperback.

There have been some changes from the third and earlier editions but one n still assign the conception of this book to the immediate post-war years. here are some touches of contemporary ornament, but the basic architecture shines through. Thus degrees Celsius now make their appearance in most, but not all, parts of the book; on p. 18 there is a passing reference, quite out of context, to the 26-month upper wind periodicity, and on p. 29 in the discussion of the formation of raindrops we have the bare statement that 'simple coalescence undoubtedly occurs'. But the changes in meteorological thinking during the past 20 years have been so great that these alterations are not enough; some of the older examples, references and material should now be discarded and more recent well-established explanations should take their place.

The aim of this book 'to fill a gap in the literature of physical geography . . . chiefly in the no-man's land of dynamic climatology' is as laudable now as it was in 1953, and eight printings during the last nine years testify both to the fact that this book successfully achieved its aim and that there is a continuing need for a book of this type. Is it too much to hope that for the fifth edition the author will undertake a substantial amount of revision?

R. J. OGDEN

NOTES AND NEWS

The Mk 3 and Mk 3b radiosondes

The prototype, Mk 3, and pre-production model, Mk 3b, radiosondes are shown in Plate IV. The smaller version is made possible by the excellent thermal insulation properties of foamed polystyrene. A fine resistance wire is used to sense temperature while an improved aneroid is used to measure pressure. Humidity values are provided by gold-beater's skin as in the present Mk 2b radiosonde. The improved performance of the sensors is preserved in transmission by the inclusion of reference signals. The printed-wiring unit visible in the photograph is a 24-way motor-driven switch which provides an extensive choice of signal pattern. With the pattern currently in use, temperature data are signalled every four seconds and humidity data every eight seconds.

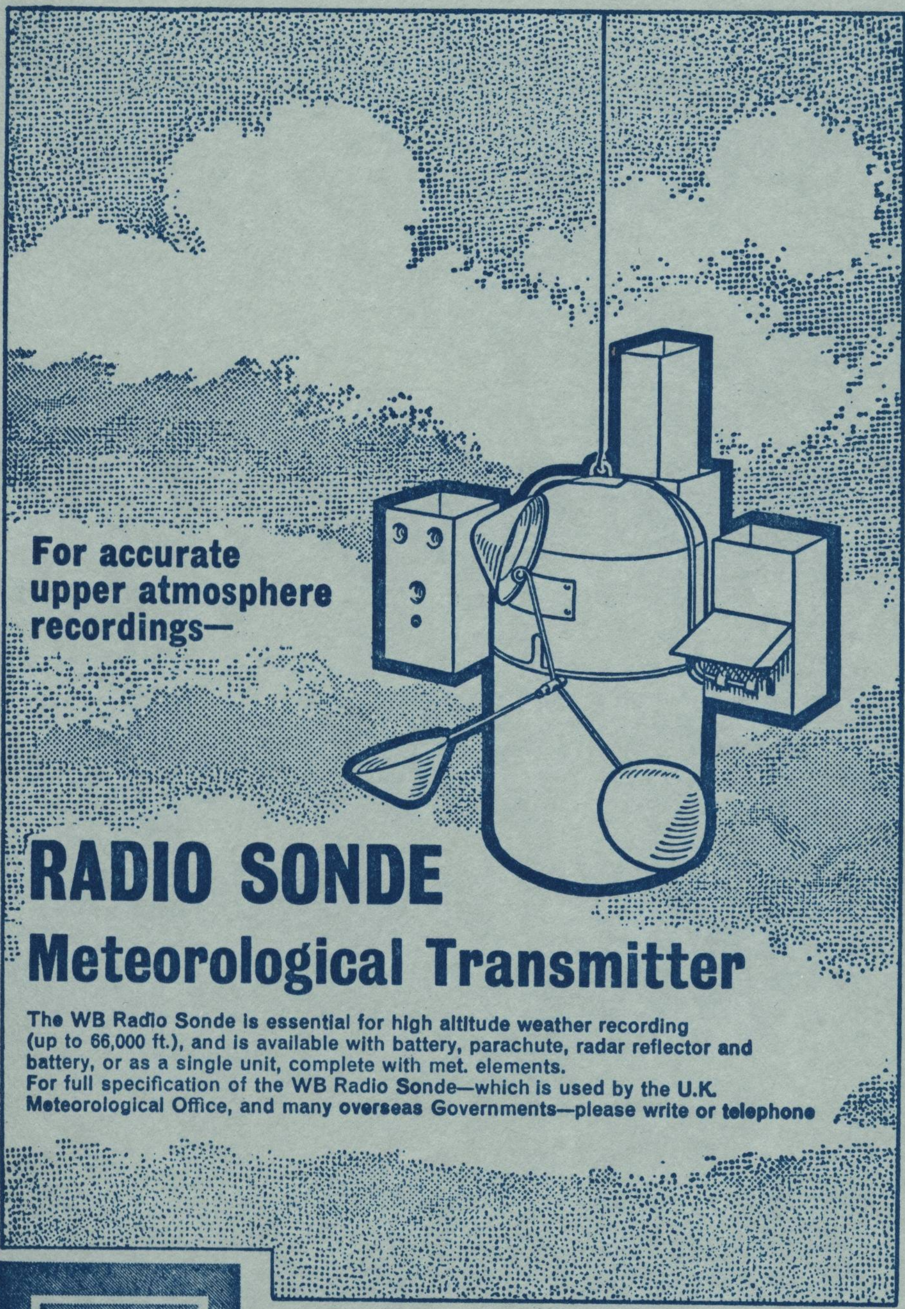
OBITUARIES

It is with regret that we have to record the deaths of Mr W. C. P. Taylor (S.S.A.) on 14 December 1966 and Mr F. E. Coles (P.S.O.) on 11 February 1967.

CORRIGENDUM

It is regretted that the following error occurred:

Meteorological Magazine, January 1967, p. 31, Notes and News; for 'Director-General of Observations' read 'Director-General of Observatories'.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The WB Radio Sonde is essential for high altitude weather recording (up to 66,000 ft.), and is available with battery, parachute, radar reflector and battery, or as a single unit, complete with met. elements.
For full specification of the WB Radio Sonde—which is used by the U.K. Meteorological Office, and many overseas Governments—please write or telephone

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