

AIR MINISTRY
METEOROLOGICAL OFFICE

Scientific Paper No.3

The Rainfall of Malta

by B. F. BULMER, M.A., B.Sc. and
K. STORMONTH, B.Sc.

LONDON: HER MAJESTY'S STATIONERY OFFICE

PRICE 3s. 0d. NET

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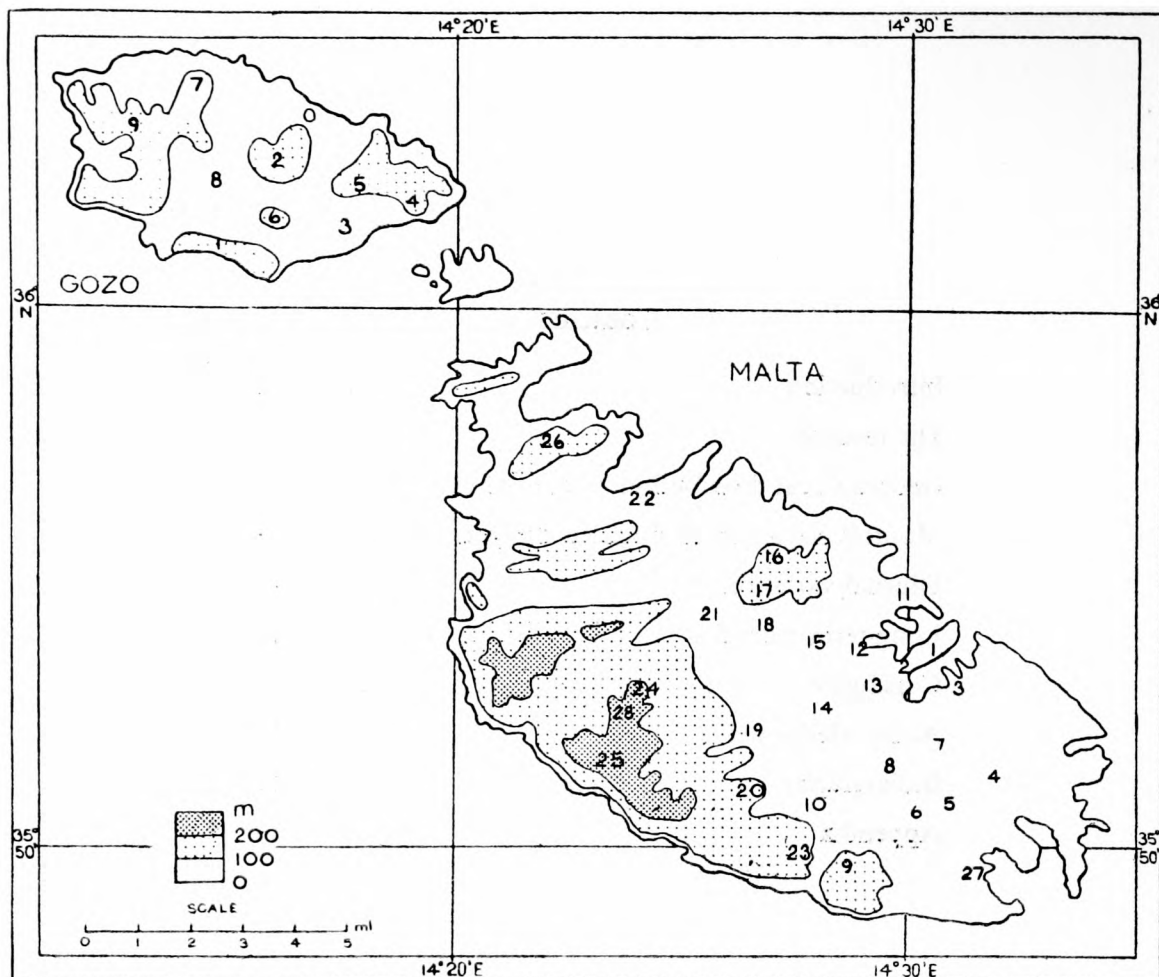
LONDON
HER MAJESTY'S STATIONERY OFFICE
1960

Printed in England under the authority of HER MAJESTY'S STATIONERY OFFICE by
James Townsend & Sons Ltd., Exeter

W1.4117 BM4392 K7 6/60

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FRONTISPIECE. Key map of Malta and Gozo

Malta

- | | | |
|-------------|----------------|--------------------|
| 1. Valletta | 11. Sliema | 20. Siggiewi |
| 2. Floriana | 12. Msida | 21. Mosta |
| 3. Kospikwa | 13. Hamrun | 22. St. Paul's Bay |
| 4. Zejtun | 14. Qormi | 23. Qrendi |
| 5. Axiaq | 15. Birkirkara | 24. Mdina |
| 6. Gudja | 16. Gargur | 25. Dingli |
| 7. Tarxien | 17. Naxxar | 26. Mellieha |
| 8. Luqa | 18. Lija | 27. Birzebuggia |
| 9. Zurrieq | 19. Zebbug | 28. Rabat |
| 10. Mqabba | | |

Gozo

- | |
|----------------|
| 1. Sannat |
| 2. Xaghra |
| 3. Ghajnsielem |
| 4. Qala |
| 5. Nadur |
| 6. Xewkija |
| 7. Zebbug |
| 8. Victoria |
| 9. Garbo |

The Rainfall of Malta

by B. F. Bulmer, M.A., B.Sc. and K. Stormonth, B.Sc.

INTRODUCTION

Rainfall measurements are known to have been made in Malta for well over 100 years. In this highly populated island the water supply is barely adequate when the rainfall is normal. When it falls below normal a serious situation arises, since the water deteriorates in quality and becomes brackish as the supplies decline. Thus the people of Malta are more than usually concerned with variations in rainfall and it is probable that measurements of some kind were made far back into antiquity before those of which we have definite knowledge.

Several writers have already compiled summaries of the Malta rainfall but these have either covered relatively short periods or, when a long period has been covered, the record has been compounded of different periods for different places. As the present paper will show, there is a considerable variation in the rainfall in different parts of the island even when averaged over a long period and consequently it is undesirable to compound records from different locations without going into the details of the inter-relation between them and, if necessary, adjusting the figures to a common standard.

One aim of the present paper is to produce a homogeneous record of rainfall in Malta extending over a period of 100 years and referred to a standard location. Related aims are to map the distribution in space over the island and to consider the variation of rainfall with time. The hourly variation of rainfall through the day, the monthly variation through the year and finally the variation of the annual totals through the years will be considered. It is hoped that some of the conclusions reached from a consideration of the reasons for the particular distributions in time and space which are revealed, may throw some light on the more general problem of the distribution of rainfall on a fairly small island.

Since it is proposed to compare the records for different locations and to consider distribution patterns, it will be well to make a brief study of the geography of the Maltese islands. The Frontispiece shows the general disposition of the islands with Malta, the largest island, to the south-east, Gozo to the north-west and the small island Comino lying between. This will be used as a key chart and shows the positions of the various towns and villages to which reference is made.

Malta, the most highly populated island, has high ground in the west and south-west rising to 600–800 feet but the east is relatively low lying and has many arms of the sea penetrating one or two miles inland. Contours are shown for the 100-metre (328-foot) and 200-metre (656-foot) levels. The ground above the 200-metre level, on which lie the towns of Rabat and Mdina, is commonly referred to as the Rabat Ridge. This, together with the similarly high ground immediately to the west, is commonly called the Rabat Plateau. This plateau is important as the main water catchment and storage area for the island.

Gozo has hills rising to about 600 feet in the west but its topography is very complicated and there is no large area of low ground. There are no large intrusions of the sea as in Malta. Comino is small and of little importance.

Having discussed the salient points of the Malta topography we shall be in a position to compare the actual rainfall distribution maps, which have been compiled, with the distribution which might have been expected if relief and aspect were the sole consideration. The details of the spatial distribution are considered on pages 3 to 9. Here it may suffice that, since there is an appreciable variation from place to place, the various records must be carefully considered and compared before deciding on a place of reference for a single homogenized long-term record.

THE RECORDS

There are four main sources of data, namely:

(a) *Water Department records*

These records are the averages of several gauges situated on the Rabat Plateau. This source provides an uninterrupted record from 1883 to 1953. Earlier figures covering the period 1851 to 1869 were recorded by Chadwick,^{1, 2*} senior adviser to the Water Department, and it is probable that these figures refer to the plateau, this being the main catchment and storage area and the one in which Chadwick was primarily interested, although there is no certainty that the rain-gauges were in precisely the same places as in later years.

(b) *Royal University of Malta records*

The records of the Royal University of Malta at their Observatory in Valletta provide an uninterrupted record from 1904 to 1954.

(c) *Elementary schools' records*

The records from the elementary schools provide reports from a number of villages scattered over the islands and are especially important in that they provide a reasonably close network of observing stations from which the geographical distribution of rainfall throughout the island may be studied. A mean value computed from six of these schools was published as the official Malta rainfall figure over the period September 1869 to August 1883 when no independent record was published by the Water Department, thus covering the gap mentioned in paragraph (a). The schools record was later interrupted twice by the two World Wars. Between these two wartime gaps in published data, a period of 15 years from 1924 to 1938 has been chosen on which to base the study of the spatial distribution.

(d) *Meteorological Office records*

The records of the Meteorological Office commenced in 1922 but major changes in the location of the gauges occurred, notably on the move from Valletta to Luqa in June 1946. The chief interest of the Luqa records is that from 1947 onwards *hourly* observations of rainfall are available and thus this source provides the detail, lacking in the long-period records, from which diurnal variation and also the frequency of occasions of rain of various intensities can be investigated. Facts emerge from the study of diurnal variation which have a useful bearing on the interpretation of the spatial distribution over the islands.

* The superscript figures refer to the bibliography on p. 18.

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Erratum

**Page 3, Figure 1 ; The mean annual rainfall at Mdina should
read 26·8 inches and not 26·3 inches.**

GEOGRAPHICAL DISTRIBUTION OF RAINFALL

This is deduced from the records of the Government schools which provide a comprehensive network of observations. From this source Figure 1 has been drawn showing the mean annual distribution of rainfall in inches over a period of 15 years from 1924 to 1938. The

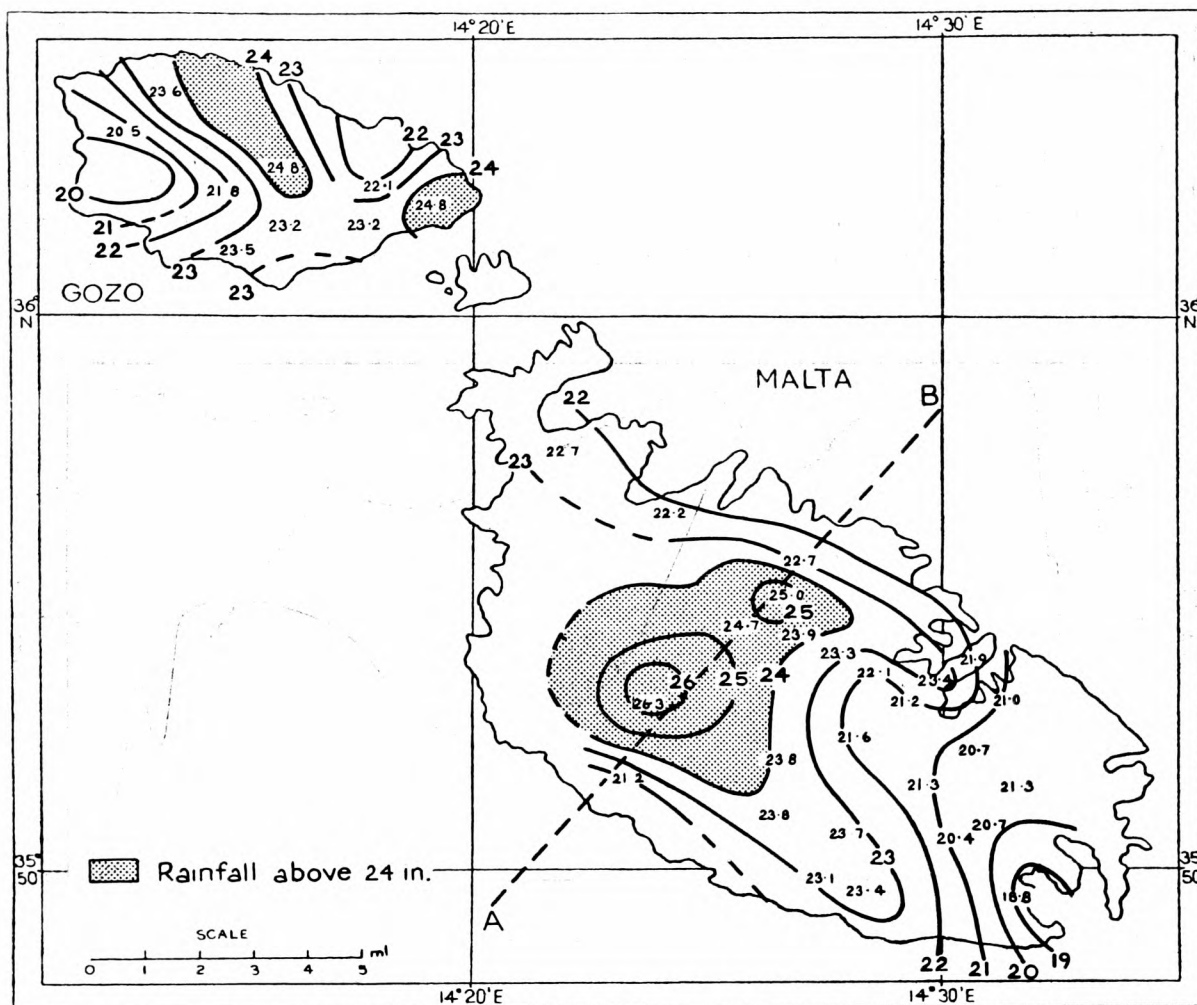


FIGURE 1. Distribution of mean annual rainfall

AB represents the line through which the cross-section, Figure 2, is drawn

distribution over Malta will be discussed rather than that over Gozo because, apart from the greater amount of observational data available for the larger island, Malta is more clearly divided into low ground and high ground. The reporting stations in Gozo are mostly at an intermediate level (between about 300 and 450 feet) and the island's geography is complex. Whether from these or other causes, the patterns of distribution for the various months over Gozo are not well marked or coherent enough to justify the formulation of any theories regarding them.

The distribution over Malta is not an immediately obvious one and calls for comment. Since the predominant wind is north-westerly and the highest ground is in the west it might

be expected that the greatest falls would be on the highest ground, especially where exposed to the north-west. Instead, we find the area of maximum rainfall in the central part of the island with an extension south-eastwards to the villages of Qrendi and Zurrieq and another towards the great harbours. It should be noted that the highest-level station, Dingli, has 21.2 inches which is one of the lowest falls, while the relatively low-lying station, Mosta, has 24.7 inches which is one of the highest falls. The area of lowest rainfall is in the region of Marsaxlokk in the south-east of the island. This is in accord with the expectations, since this area is both low lying and is at the leeward end of the island with a long land track in respect of the predominant wind.

It is the area of highest rainfall which provides food for thought. Roughly speaking, the rainfall increases to a maximum in a region slightly to the west of the geographical centre of the island and this with relatively little regard to land contours. The land contours doubtless do exercise some control in the usual sense but this is much complicated by other factors.

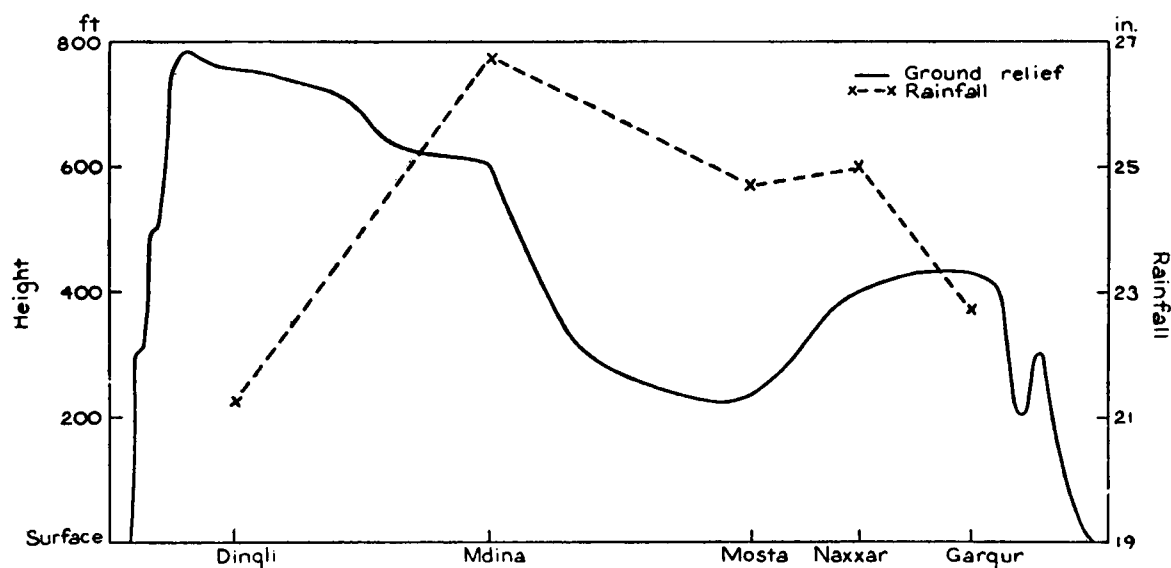


FIGURE 2. Distribution of mean annual rainfall compared with altitude above mean sea level

This cross-section is drawn through the line AB in Figure 1

Referring to Figure 1 let us consider the cross-section A-B, the line of which lies roughly athwart the prevailing wind. Five stations lie on, or very close to, this line and Figure 2 represents the cross-section through these stations showing the comparison between the variation of ground level and mean annual rainfall. Proceeding from A to B the first station, Dingli, is the highest in altitude and the lowest in rainfall. The next station, Mdina, has the highest rainfall on the island (26.8 inches). This place lies on a spur of rock which catches the prevailing winds. It is lower in altitude than Dingli but it is still a high-level station. The third station, Mosta, is relatively low lying, yet its rainfall, 24.7 inches, though appreciably less than that of Mdina, is the third highest on the island. The fourth station, Naxxar, on appreciably higher ground than Mosta and exposed to the north-west, has 25.0 inches, the second highest on the island. The last station, Gargur, with 22.7 inches, represents a considerable decrease and this in spite of the fact that it is at about the same altitude as

Naxxar and, from the point of view of exposure to the predominant wind, might well have been expected to show an increase over the latter. All these stations, with the exception of the middle one, Mosta, are high-level stations. Making allowance for altitude and some topographical effects upon the wind, it would seem, therefore, that there is a tendency for a maximum of rainfall towards the centre of the island with a decrease towards the coast in both directions.

Other main features of the distribution of mean annual rainfall, to be seen from Figure 1, are the relatively high rainfall extending south-eastwards from the Mdina maximum towards the village of Zurrieq and the area of minimum rainfall around Marsaxlokk, whence relatively low rainfall continues north-westwards towards Msida.

Before seeking to interpret the distribution pattern of annual rainfall it will be well to consider some of the individual months from which it is compounded. Figures 3, 4, 5 and 6 show, respectively, the mean distribution of rainfall for the months September, October, December and March. It will be seen that there is considerable variation in the distribution

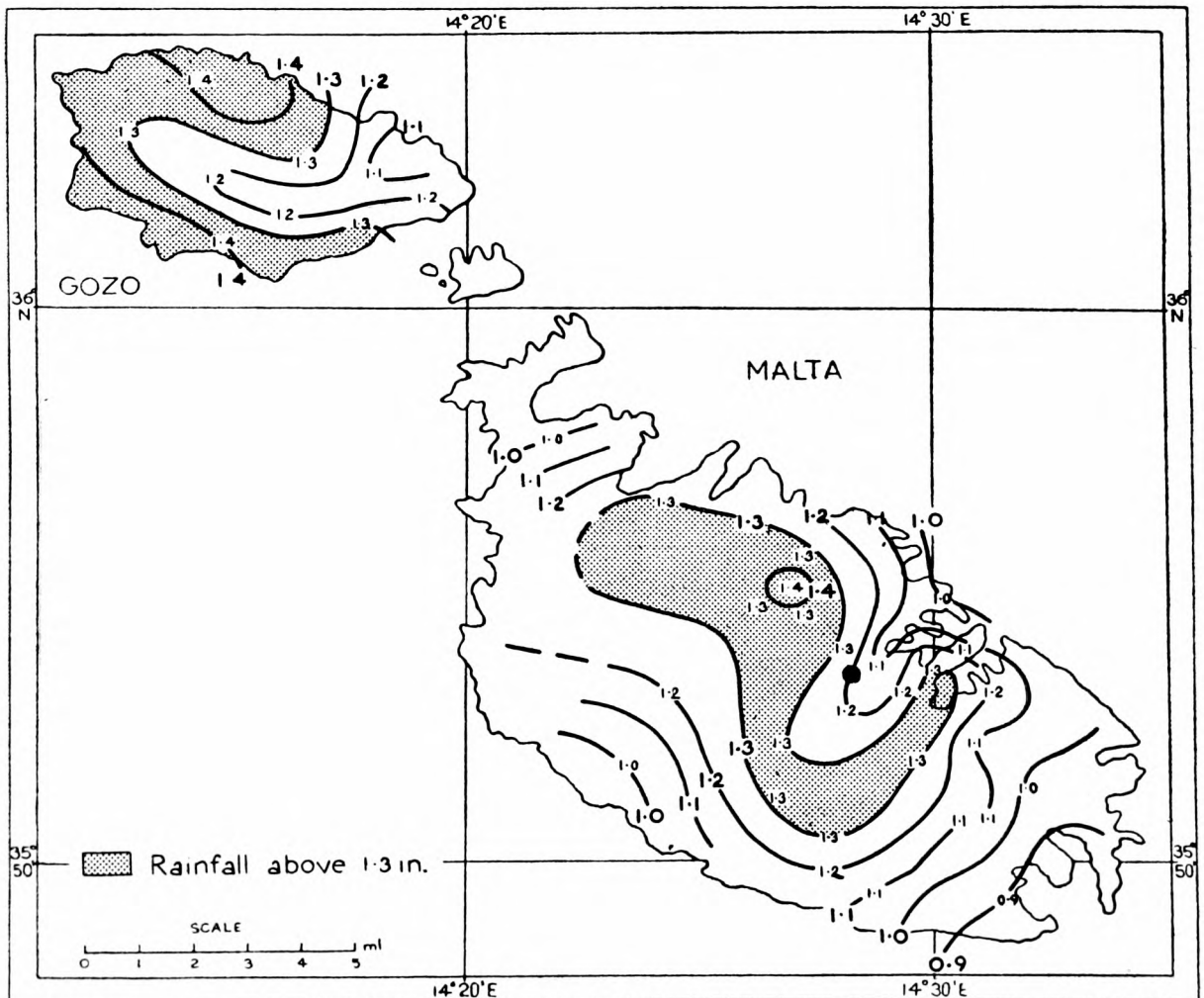


FIGURE 3. Mean monthly rainfall distribution for September

pattern according to season, which gives an idea of the essentially complex nature of the resultant annual pattern. Of special interest is the distribution for September which may be taken as characteristic of the summer régime when the rainfall, though small, is almost wholly convective. It will be seen from Figure 3 that there is a complex area of high rainfall with a maximum at Naxxar and a secondary maximum in the Luqa-Siggiewi area with an extension towards the great harbours.

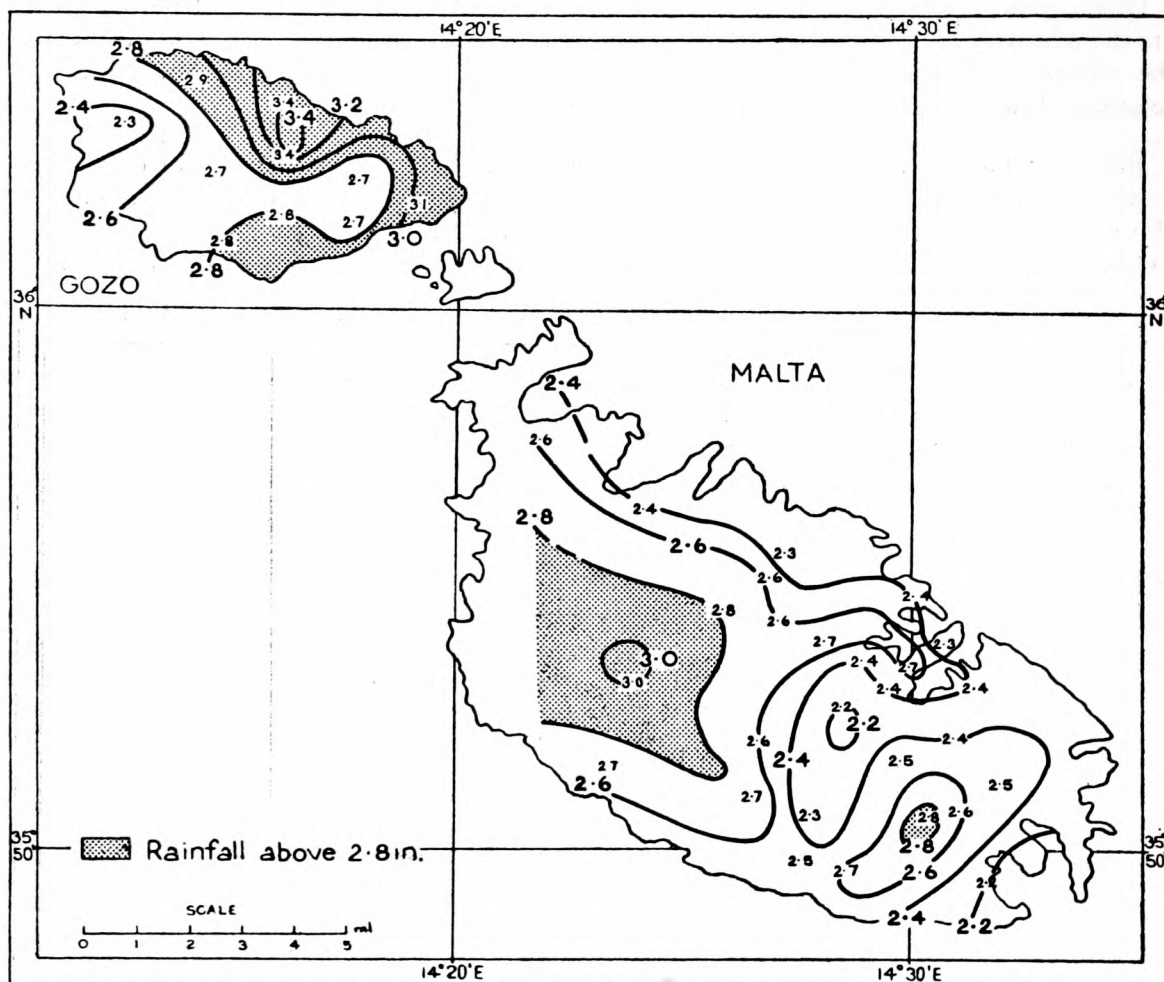


FIGURE 4. Mean monthly rainfall distribution for October

Lamb³, writing on Malta's sea-breezes, has established that in situations of little general wind there tends to develop, in the summer months, a convergent system of sea-breezes primarily north-easterly near the north-east coast and south-westerly near the south-west coast, which in many cases ultimately results in a closed anti-clockwise circulation about a centre not far from the airfield at Luqa. Lamb refers to convective cloud reaching a maximum of development over the centre of circulation and to nearly stationary showers associated therewith. This would agree well with the view that the secondary maximum of rainfall in the Luqa-Siggiewi area is associated with the centre of thermal convection.

The fact that slightly higher rainfall is observed in the region of Naxxar is probably due to the complications of topography. Naxxar (400 feet) is appreciably higher than the stations in the Luqa-Siggiewi area, which alone might explain its slight excess. Naxxar may be expected to get the heavier rainfall on days when the north-west wind is blowing. On days when the Malta sea-breezes fully establish the island's own convective circulation with its centre in the Luqa-Siggiewi area, moist air from the largely inland waters of the twin harbours surrounding Valletta will flow towards the interior of the island near the centre

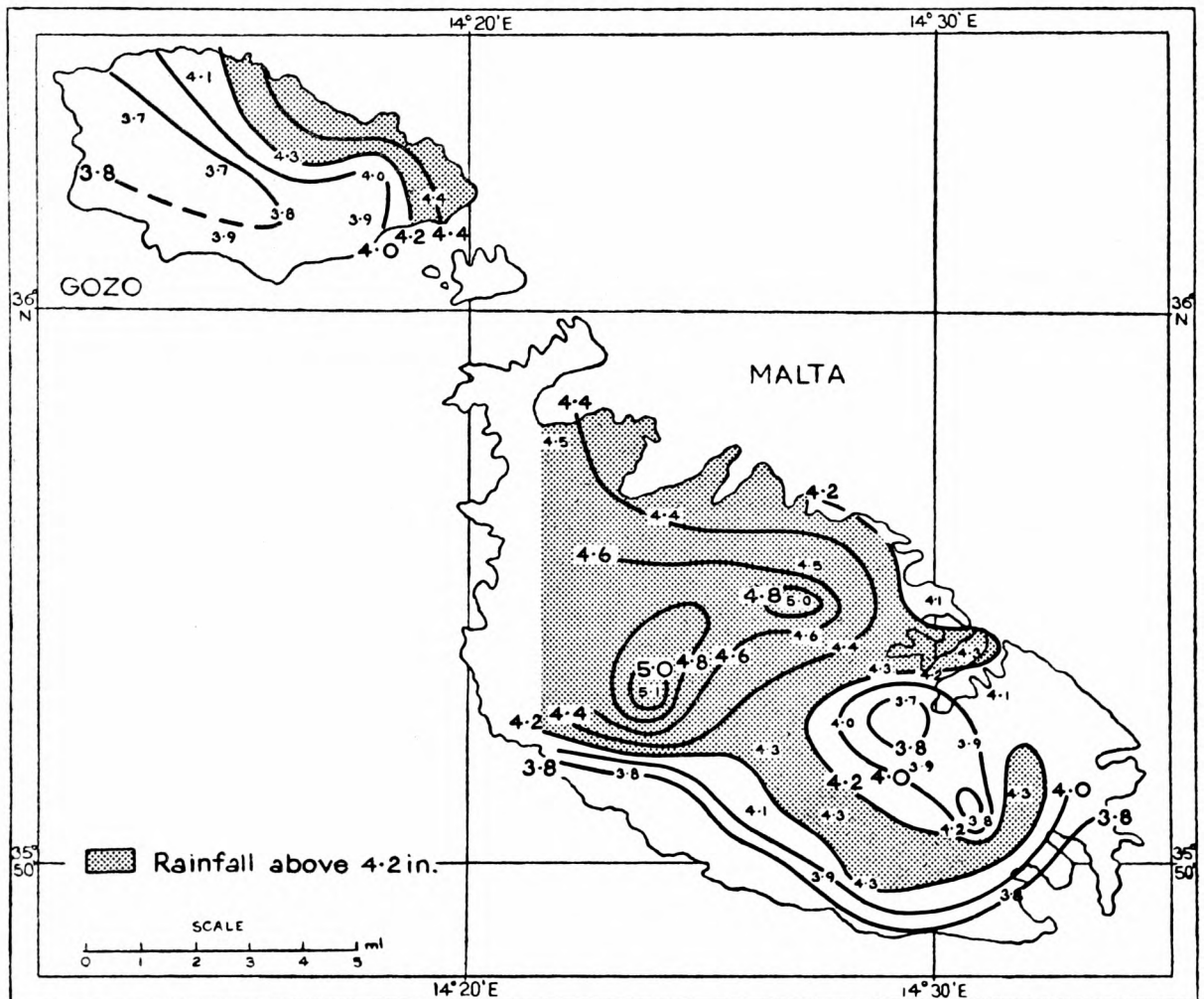


FIGURE 5. Mean monthly rainfall distribution for December

of the circulation, giving the heaviest rainfall at places like Floriana and Luqa where there has been some uplift of the air over rising ground as well. The still higher ground at Mdina is appreciably farther away from this source of moisture. Moreover, a further reason why the September rainfall of Mdina should be less than that of Naxxar may be found in that the position of the sea-breeze convergence line (Lamb, loc. cit. Figures 3 and 4³) lies close to Naxxar on the frequent occasions of north-westerly gradient winds and only approaches Mdina on the rarer occasions of south-easterly gradient winds. It is thought that this September distribution map, since it gives a picture of the distribution due primarily to

convection, gives an important clue to the interpretation of the more complex mean annual distribution map. The latter distribution is thought to be ascribed primarily to the combination of the largely convective distribution, typified by the September map, with an increased contribution due to the relief of the island in the other seasons. Further factors are exposure, relative to the prevailing winds, and the presence of large intrusions of the sea in certain areas.

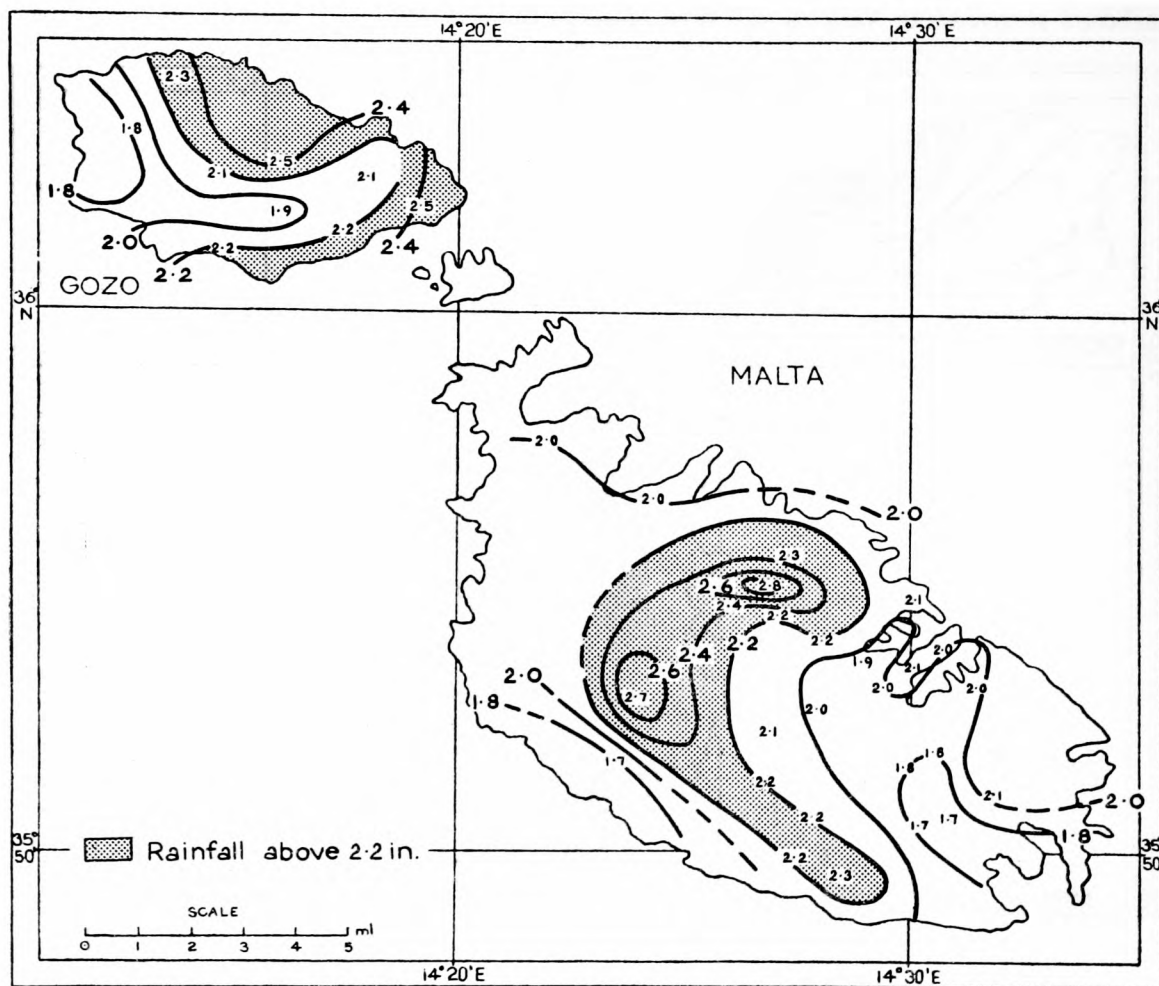


FIGURE 6. Mean monthly rainfall distribution for March

The map for October (Figure 4) is appreciably different from that for September. The displacement of the maximum from Naxxar to Mdina and the development of an extension of the maximum through Siggiewi and Qrendi to Gudja suggests that topography is beginning to play an important part at this season.

Figure 5, which shows the distribution in December, shows a nearer approximation to topographic control, though even at this time of year the pattern of the ground contours is strongly modified by a tendency for higher values remote from the coast. Where we have low ground near the coast, as in the Marsa area (at the head of the Grand Harbour) and

at Birzebuggia, the rainfall is lowest; where we have high ground well away from the coast, as at Mdina and Naxxar, the rainfall is highest.

Figure 6, giving the March distribution, shows some approximation to distribution according to height but with the same tendency for lower values near the coast, even where the ground is high. In common with the *annual* distribution map it shows the lowest values near Marsaxlokk with relatively low values extending thence towards Msida.

It will be seen from the foregoing that from October to March, that is, in all months of considerable rainfall, the maximum is in the Mdina–Naxxar region and there is a minimum around Marsaxlokk, although over the eastern end of the island there is more variation of distribution according to season. Thus, in December, a minimum in the Hamrun–Marsa area rivals that over Marsaxlokk and values are rather higher in between, that is, in the Gudja–Zejtun area. This area of slightly higher rainfall is also present in October but in other months, for example March, this disappears and low values persist all the way from Marsaxlokk to Msida. This latter pattern evidently predominates as it is to be seen on the *mean annual* map (Figure 1). Some of these variations in the geographical pattern from month to month within the same season may however be attributable to chance effects in the 15-year sample of observations used.

Regarding the apparently anomalous position of Dingli, which while being the highest reporting station has one of the lowest rainfalls both as regards annual total and in most individual months, the convectional bias towards the centre of the island cannot wholly explain this. Dingli is little nearer the coast than Gargur which has a higher rainfall. A further factor which may help to explain the apparent anomaly is the existence of a steep north-west facing escarpment running across the island from near Gargur in the east to a position roughly along the north side of the most northern 200-metre (656-foot) contour in the west (see the Frontispiece). This escarpment is a sufficiently pronounced geographic feature to have been converted into an old line of fortifications, the Victoria Lines. Now the line of stations from Gargur to Dingli, reviewed in diagrammatic form in Figure 2, diverges from this escarpment line progressively from east to west, so that whereas Gargur and Naxxar are quite close to the escarpment, Dingli is several miles to leeward. Added to this, a considerable area of high ground (about 700 feet above sea level) lies between the main escarpment and Dingli, and in the prevailing north-westerly situation it is probable that much of the rain which would otherwise reach Dingli falls on this northern part of the plateau. By comparison Mdina, considerably nearer the main escarpment, is shielded by only narrow ridges of high ground and the ground drops abruptly from it on most sides so that local updraughts are likely to be important.

MONTHLY VARIATION THROUGHOUT THE YEAR

Figure 7 shows the variation of rainfall, month by month, throughout the year. Here the mean monthly rainfall during the period 1921–50 is plotted both for the plateau gauges and for the University, Valletta.

During this 30-year period the highest average rainfall on the plateau was reached in December when the mean fall was 4.66 inches. This declined steadily through January and February. March showed a slight slackening in the monthly rate of decrease but after March there was a rapid decline and from May to August inclusive the mean rainfall was

negligible. September showed an appreciable increase and by October there was a sharp rise to 2.67 inches and thereafter a more gentle climb to the December peak.

The curve for the Valletta rainfall is similar in its general form. December was again the wettest month and the period May to August was again very dry. The values for Valletta were rather below those of the plateau mean, the difference being at a maximum in November and December when Valletta had about half an inch per month less than the plateau. In contrast, in May the Valletta average slightly exceeded that of the plateau.

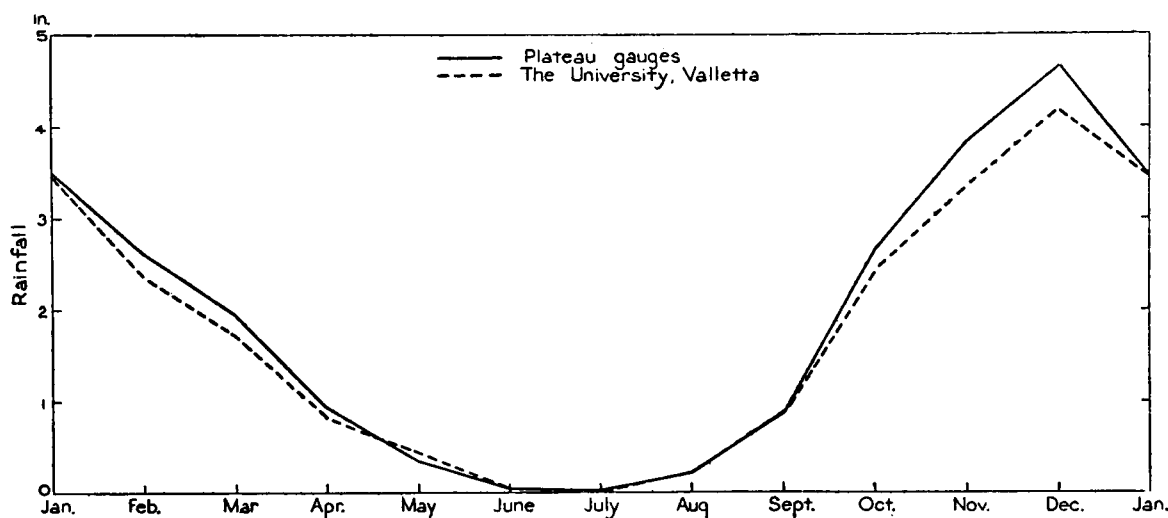


FIGURE 7. Mean monthly rainfall for the period 1921-50

It might well be wondered why, for this relatively recent 30-year mean, the latest possible 30-year period has not been chosen. This is because of the altogether phenomenal rainfall of October 1951 which broke all records and which, if included, would result in a non-representative graph unless a very much longer period were used. The use of a very long period might have the disadvantage of introducing some degree of change of climate. Thus the period chosen is the latest 30-year period which is representative.

In order to give an idea of the degree of abnormality of 1951, Figure 8 shows the monthly variation of rainfall for the plateau, based on figures for the 10 years 1944-53. In spite of averaging over 10 years, the graph shows October as the wettest month of the year—this distortion being almost entirely due to the rainfall of October 1951 when 14.9 inches fell on the plateau and 19.9 inches at Luqa. Several places experienced a normal year's rainfall in this one month. Thus Floriana reported 23.8 inches for the month of October 1951, this being the highest monthly figure ever recorded in Malta. The spatial distribution of rainfall for the abnormal October of 1951 is shown in Figure 9 which indicates higher values in the general area of Valletta and the twin harbours than elsewhere. While discussing abnormal falls it may be of interest to record that the highest annual fall recorded in Malta was 40.32 inches also at Floriana (Argotti Gardens) in 1951. The highest daily fall recorded was at Kospikwa in October 1912 when 16 inches fell.

In spite of the abnormality of the falls of October 1951 which make the monthly variation curve of Figure 8 unrepresentative, it will be seen later that a sufficiently long period including the freak year 1951 confirms the normal distribution shown by Figure 7.

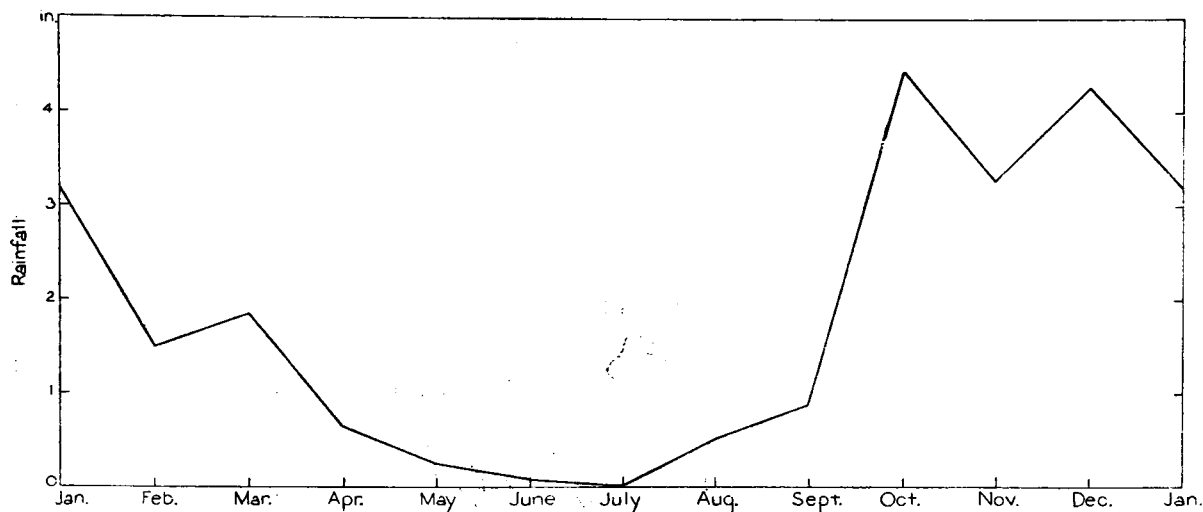


FIGURE 8. Mean monthly rainfall for the plateau for the period 1944-53

This is an unrepresentative curve due largely to the abnormal falls of October 1951 when 14.9 in. fell

As regards divergence from the normal seasonal distribution, the most frequent variation takes the form of a shift in the timing of the commencement of the wet and dry seasons. Although liable to large variations, the midwinter months can usually be counted upon to contribute about two to five inches per month. Similarly June and July can normally be relied upon to have negligible rain. It is the intermediate months of April, May, August and September which are each liable at times to be dry, causing frequent variations in the timing and extent of the dry season. For example, 1943 was dry (on the plateau) from the beginning of July to the end of September. In contrast, in the previous year it was dry from the beginning of April till the end of July. In 1953 there was no rain from the beginning of April till the end of September, although the annual rainfall this year was not abnormal. In individual years any month from October to March may be the wettest. Even December, which on the average is the wettest month, has on occasion been rainless. In order to compare the variability of the rainfall in different months, standard deviations have been calculated for the months September to May over the years 1854-1953 inclusive (100 years). The values are:

Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
				<i>inches</i>				
1.38	2.51	2.18	2.65	2.13	1.41	1.54	0.90	0.62

These values divided by the mean for the month in question and multiplied by a hundred give the 'coefficient of variation' (Brooks and Carruthers⁴) which is a measure of the comparative variability of rainfall in the various months. These coefficients of variation are:

Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
131.4	84.5	56.6	32.6	61.5	64.5	92.8	144.7

It will be seen that the comparative variability is least in December and increases progressively in both directions towards the dry season. Although April and September show the greatest values, the mean rainfall concerned in these months is only of the order of one inch. March and October come next in order of comparative variability. As the

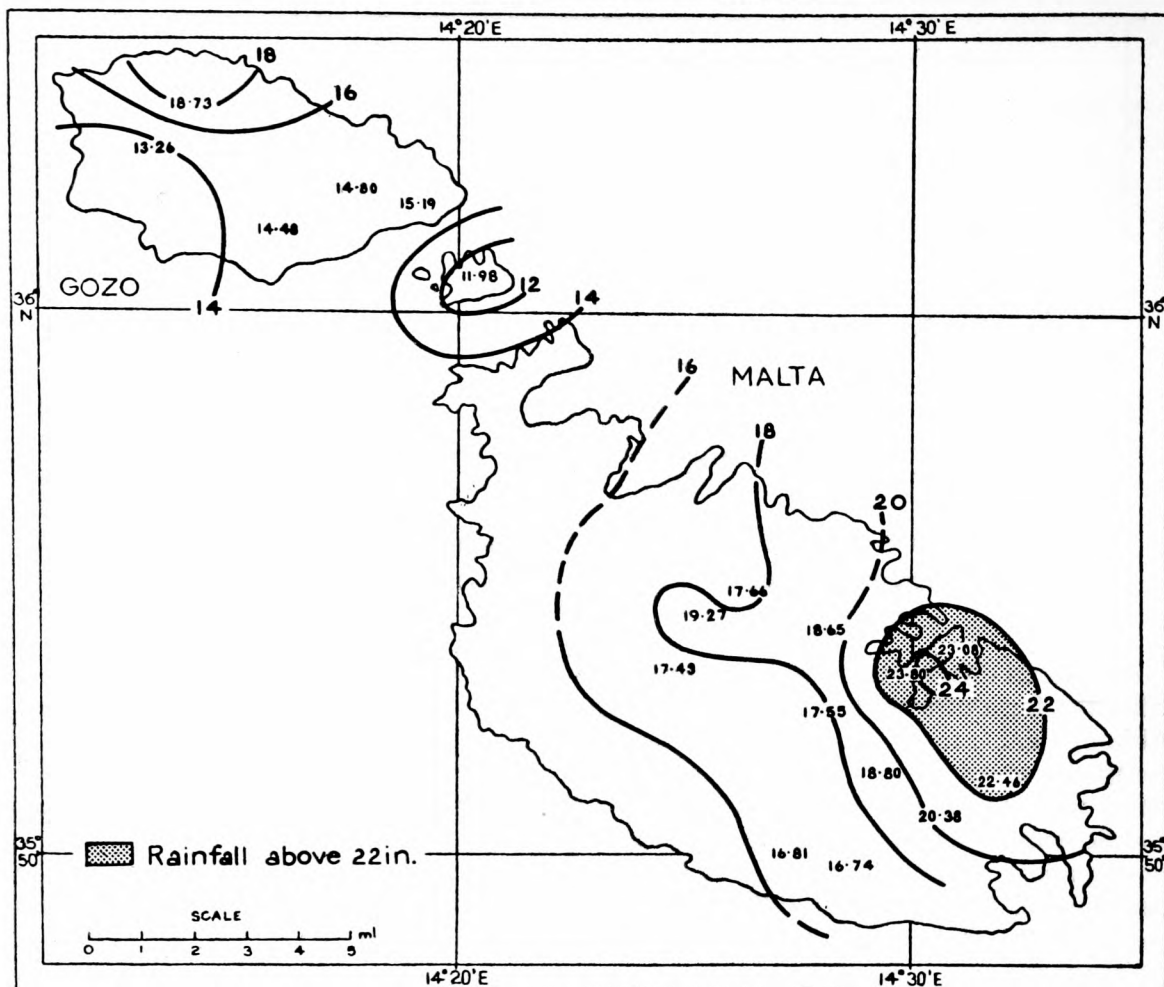


FIGURE 9. Monthly rainfall for October 1951

This was an abnormal month in which figures within the shaded area exceeded Malta's average annual fall

mean October rainfall is considerably in excess of March it is thought that the relatively high variability of the October rainfall is of more significance than are the higher variability in months of lower rainfall.

DIURNAL VARIATION

For details of the mean variation of rainfall through the day we must turn to the records of the Meteorological Office at Luqa. These have been analysed for the period 1947-56 and Figure 10 shows the hourly variation of mean rainfall and the hourly variation of mean intensity. The latter was measured by dividing the total rainfall for the hour in question during the ten-year period by the total duration within the same hourly period.

It may be noted that the period chosen (the only available long period of hourly observations) includes the phenomenal October 1951. However, it was the monthly total which was especially outstanding and there is no evidence that the distribution according to hour

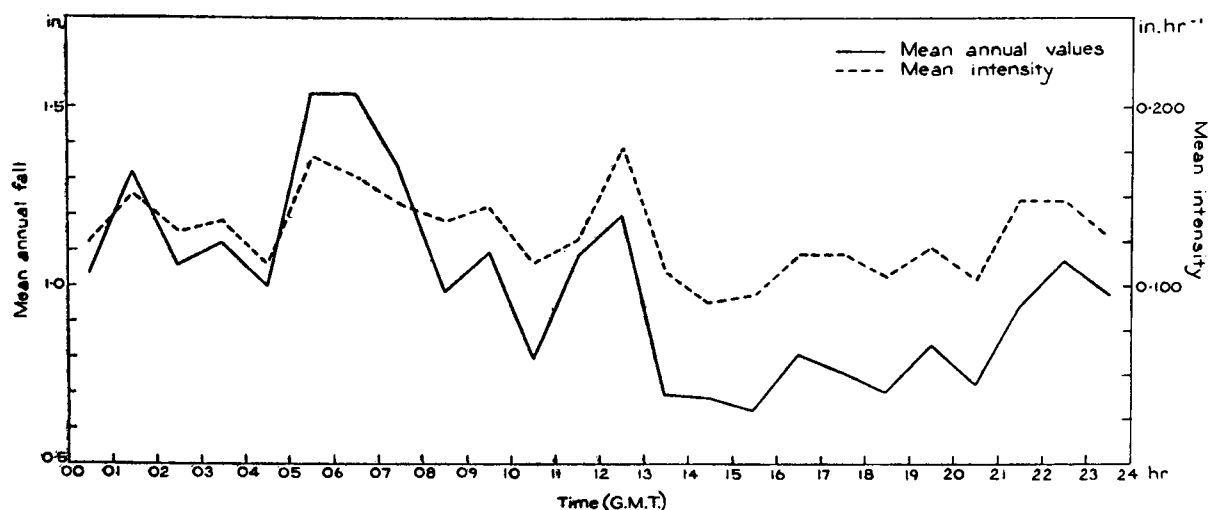


FIGURE 10. Diurnal variation of the mean annual values and the mean intensity of rainfall for each hour of the day over the period 1947-56 at Luqa

of day of the many individual falls, which went to make up the total, was especially abnormal.

It will be seen from the curve of hourly variation of mean rainfall that, in general, more rain falls during the night than during the day. In this connexion it may be important to remember that most of the rain falls in the winter half-year when the solar heating of the ground becomes least important. The maximum is seen to be reached around 0600 G.M.T., then falling off rapidly. This is in accord with the convective cycle over the sea where cooling from the tops of clouds proceeds through the night, tending to produce increasing thermal instability and increasing convection until about dawn.

We may conclude therefore that the greater part of Malta's rainfall, even at stations near the centre of the island, is governed by the rainfall régime over the surrounding sea. It is thought probable that the nocturnal marine contribution is fairly constant over the different parts of the island and that the distribution patterns discussed on pages 3 to 9 are due to factors which contribute the smaller part of the total rainfall.

If it were the marine convective cycle which exercised the sole control over the diurnal variation of rainfall, the latter might be expected to decrease progressively to a minimum in the afternoon and to increase again after dark. However, our diurnal distribution curve, while conforming in the main to this broad pattern, shows a well marked secondary maximum for the hour 1200 to 1300 G.M.T. This is thought to represent the "land convection" component of the total rainfall.

It has been shown that several factors point to the spatial distribution being partly determined by the influence of thermal convection over the land, especially in the warmer parts of the rainfall season. One of these factors is the tendency to develop a sea-breeze circulation. It is this last tendency which is thought largely instrumental in determining the timing of the secondary maximum. In general one might expect the effects of convection over the land to be felt appreciably later, in mid- or even late afternoon, but in the case of a fairly small island such as Malta, the surface temperature does not continue to rise through the afternoon in quiet situations because of the cooling due to the sea-breeze. At Luqa,

in quiet weather in September, the surface temperature normally rises very rapidly until about 1200 G.M.T. (1300 local time), then falls off slightly and oscillates about a somewhat lower value for about three hours before commencing to fall off more rapidly. The normal time at which the day maximum temperature is reached is 1200 G.M.T. and on not a few occasions this maximum is reached as early as 0900 or 1000 G.M.T. This early timing of the day maximum temperature, due to the cooling effect of the sea-breeze, may explain the corresponding timing of the secondary maximum of rainfall ascribed to land convection.

TABLE I. Diurnal variation of frequency of occurrence of hourly rainfall at Luqa, 1947-56

Hour G.M.T.	Rainfall limits					
	≥ 1.0 mm (0.04 in.)	≥ 2.5 mm (0.10 in.)	≥ 5 mm (0.20 in.)	≥ 10 mm (0.39 in.)	≥ 25 mm (0.98 in.)	≥ 50 mm (1.97 in.)
	<i>number of occasions</i>					
00-01	74	28	10	3	0	0
01-02	80	34	14	3	2	0
02-03	72	24	11	4	0	0
03-04	70	30	9	4	0	0
04-05	70	27	9	0	0	0
05-06	69	35	17	12	1	0
06-07	83	40	15	6	2	0
07-08	77	31	13	4	1	1
08-09	75	22	8	4	0	0
09-10	70	26	11	2	0	0
10-11	65	21	5	0	0	0
11-12	73	35	12	4	0	0
12-13	56	25	8	3	2	1
13-14	52	17	4	1	0	0
14-15	57	14	1	1	0	0
15-16	55	16	4	0	0	0
16-17	54	15	6	2	0	0
17-18	53	19	7	2	0	0
18-19	55	18	3	0	0	0
19-20	61	20	8	1	0	0
20-21	57	22	4	0	0	0
21-22	58	19	9	5	1	0
22-23	58	27	13	6	0	0
23-24	71	25	8	4	0	0
Totals	1565	590	209	71	9	2

Further detail regarding the hour-to-hour distribution of rainfall may be seen in Table 1 wherein the numbers of occasions of rain of various intensities are tabulated. The table shows that the number of occasions of rain of intensity equalling or exceeding 2.5 millimetres (≈ 0.1 inch) per hour rises to a well marked maximum for the hour 0600 to 0700 G.M.T., then falls off and rises to a secondary maximum for the hour 1100 to 1200 G.M.T. The period 1400 to 1700 G.M.T. shows markedly fewer occasions than any other period of the day. As progressively heavier falls are considered it is found that the general diurnal distribution remains substantially the same. For falls equal to or exceeding 25 millimetres (≈ 1 inch) per hour, the midday maximum occurs one hour later, namely 1200 to

1300 G.M.T. Some of the greatest hourly falls recorded have occurred at this time. For example, on 4 October 1951, 64.6 millimetres (2.55 inches) fell between 1200 and 1300 G.M.T. There may be some difference in the timing of the day-time maximum in different parts of the island, since places in the most central parts under the cloud masses associated with the sea-breeze convergence and convection may be expected to show the day-time maximum rainfall around the time of maximum development of the sea-breezes (c. 1300 to 1400 G.M.T.)

THE LONG-TERM RECORD

Reverting to the comparison between the four main sources of data with a view to determining a suitable reference point for a long-term record for Malta rainfall, it is found that the plateau gauges form the best standard for a number of reasons. Firstly, theirs is the longest uninterrupted record. Secondly, the rainfall in the plateau area is of more significance to the people of Malta than that measured elsewhere, since the water supply is mainly collected there. Thirdly, the plateau rainfall is somewhat more conservative than that in the eastern half of the island. Figure 11 shows a comparison between the annual totals at the Meteorological Office, Luqa and the mean of the plateau gauges. These show the latter to be somewhat more constant.

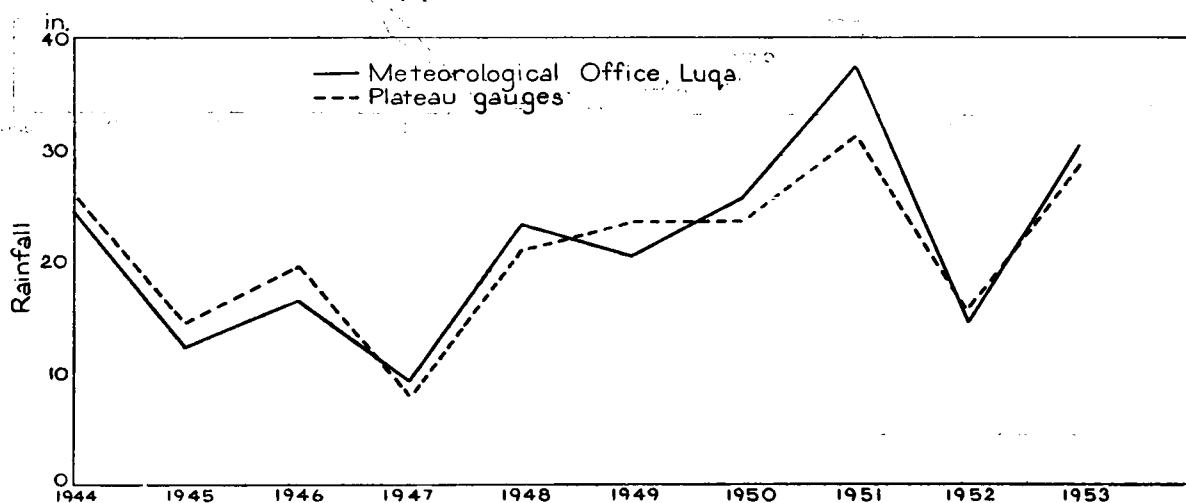


FIGURE 11. Comparison between annual totals for the Meteorological Office, Luqa, and the mean of the plateau gauges, over the period 1944-53

This figure shows the plateau values to be somewhat more constant

The Valletta record is likewise more liable to random variation than is the plateau record. The standard deviation of the Valletta annual totals, measured over the 50-year period 1904-53, is 5.63 inches while the corresponding figure for the plateau for the same period is 5.25 inches. This higher variability may perhaps be attributed to the random incidence of convection rains forming a larger proportion of the rainfall in Valletta. The plateau rainfall depends more upon orographic uplift of the prevailing winds.

Finally, it will have been seen from the section regarding the spatial distribution that there is more variation according to season in the eastern half than on the plateau.

Thus the plateau gauges are chosen as the standard of reference. To complete the long-term record of Malta rainfall it is necessary to adjust to this standard the figures for the period 1869–83 which are missing from this record but available in the “schools” record. This adjustment has been effected by comparing the parallel records of these two sources over a period of 15 years (1924–38) when both were available.

In case their inter-relation might vary with the seasons, separate conversion factors have been evaluated for each month whereby the one can be expressed in terms of the other. Figure 12 shows a comparison between the long-term monthly means of the two records.

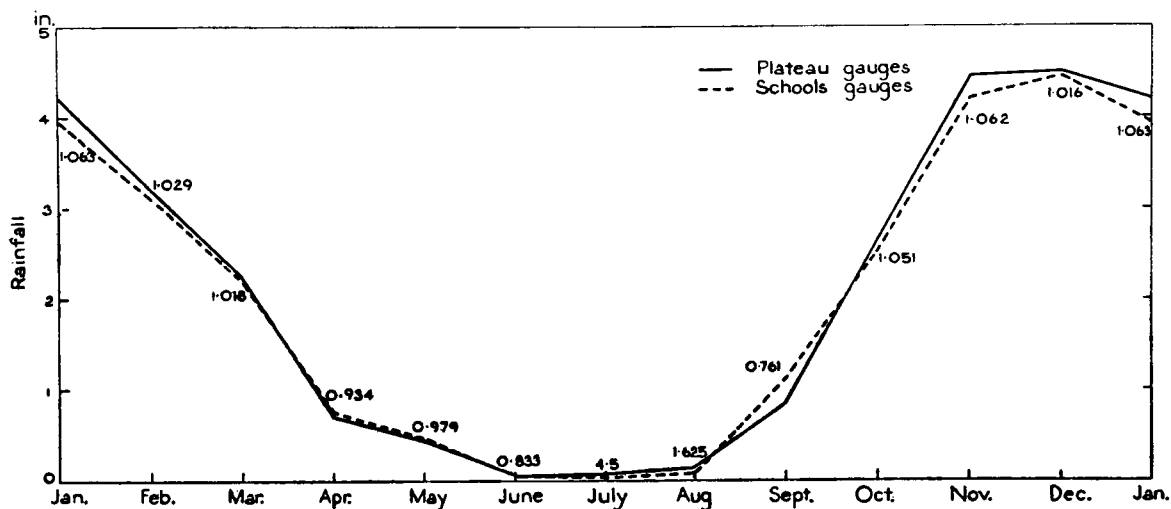


FIGURE 12. Comparison between the monthly mean rainfall recorded by the plateau gauges for the years 1924–38 and the mean of the six Government schools' records published in place of the plateau gauges during the years 1869–83

The factors recorded are those by which the “schools” record must be multiplied to obtain the “plateau” figures.

Against each month is recorded the factor by which the “schools” figures must be multiplied to give the “plateau” figures. This factor is then applied to the schools figures through the period missing from the plateau record, that is September 1869 to August 1883, so producing

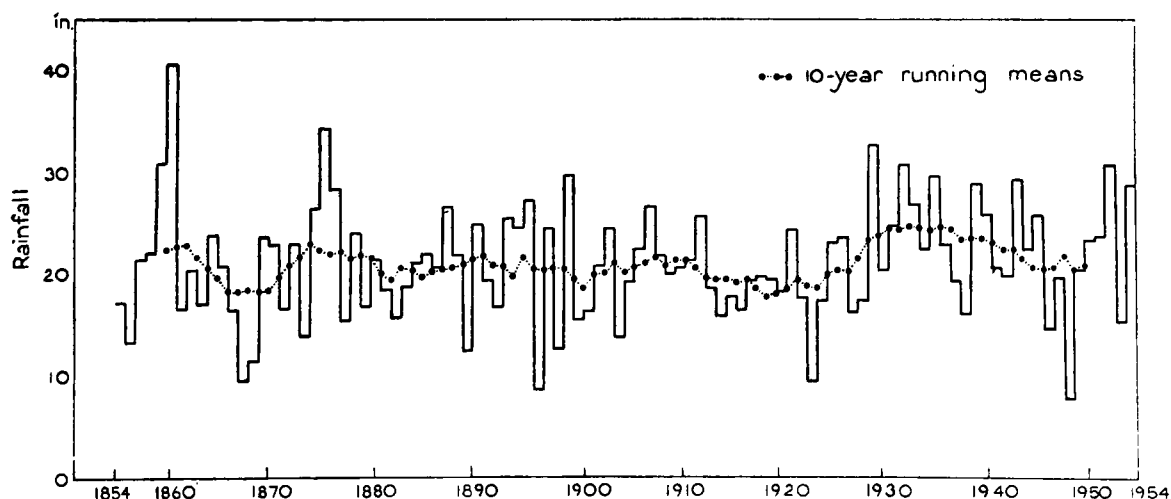


FIGURE 13. Annual rainfall adjusted to the plateau standard for the years 1854–1953

a practically homogeneous record of 100 years of Malta rainfall which is presented in detail in the Appendix. This procedure is obviously most open to question in the case of July but the Julys make only a small contribution to the total rainfall. The annual totals of this record are plotted in Figure 13 where the 10-year running means are also shown.

In order to confirm the form of the monthly variation given in Figure 7, monthly means have been calculated from the 100-year record and are shown in Figure 14. This shows that the abnormality introduced into relatively short-term means by the phenomenal year 1951 is ultimately smoothed out by taking a sufficiently long period.

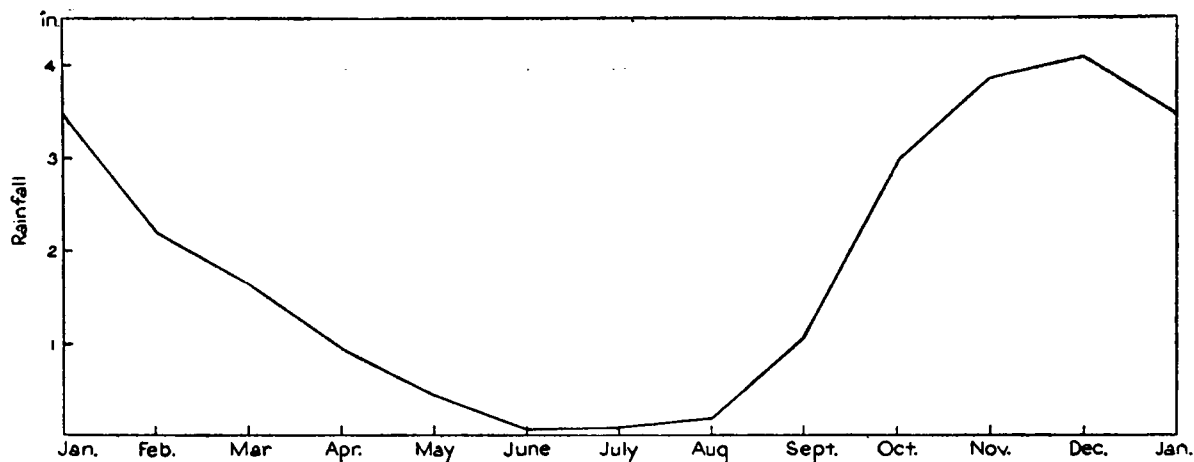


FIGURE 14. 100-year means of the average monthly rainfall adjusted to the plateau standard for the years 1854-1953

From the long record of annual totals it may be seen that, while there are large changes from year to year, for the most part the rainfall does not remain appreciably above or below normal for more than 3-4 years at a time. Running means based on 10-year periods show, on the whole, surprisingly little variation from the overall mean rainfall of 20.99 inches. An exception to this is the period 1927-43 when the 10-year running means centred on these years show the general level of rainfall to be consistently above normal. The individual years show values equal to or above normal over the 8-year period 1928-35. This does not appear to be statistically significant, although the 10-year running means remain some 15 per cent above the 100-year mean for the 7 successive 10-year periods centred on the years 1930-36. Other than this, the running means show only minor fluctuations about the mean and no significant general trend appears. Years of exceptionally high or exceptionally low rainfall do not seem to follow any simple pattern or periodicity. Very low rainfall (less than 10 inches) has been recorded at intervals of 29, 27 and 25 years but the intervals between years of a very high rainfall (above 30 inches) are much more erratic (15, 54, 3 and 20 years). This may indicate that even the comparatively even distribution of the low minima may well be fortuitous. There is no clear evidence of any correlation with the sunspot cycle.

CONCLUSION

In conclusion it may be said that, with the exceptions noted, the rainfall of Malta, in spite of its violent and apparently random annual variations, has maintained on the average a fairly constant level during the period considered, showing no appreciable secular change. It is hoped that the conclusions reached regarding the balance achieved between the diurnal

convective cycles appropriate to land and sea and also regarding the role of sea-breezes, may have some applications to the many other islands which are of such a size that neither the marine cycle nor the land cycle is wholly dominant. We know, in general terms, how the rainfall distribution varies in time and space over a large land mass and we can imagine that the very small island will have an almost wholly marine distribution. Malta is large enough to represent a compromise which may well have parallels elsewhere.

ACKNOWLEDGEMENTS

Thanks are due to Mr. H. H. Lamb of the Meteorological Office to whom the authors are indebted for the original inspiration of this paper and who has furnished the bulk of the basic data and given valued guidance to the authors. During the process of collecting the basic data Mr. A. Agius of Malta kindly assisted in providing local information and making available data compiled by the late Professor Thos. Agius of the Royal University of Malta.

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APPENDIX.—100-YEAR RECORD OF MONTHLY RAINFALL IN MALTA, 1854-1953

Figures are for, or adjusted to, the standard of the mean of the Water Department's gauges on the plateau at Fiddien Bridge, Wied Il Busbies, Bieb-Ir-Rua, Jebel Chantar, Dingli, Rabat Tank and the Rabat District Water Office.

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly totals
1854	2.1	3.5	0.4	0.4	0.6	0	0	0.5	0.6	1.8	2.4	4.8	17.1
1855	1.9	0	3.2	4.2	0	0	0	0	0	0.3	2.4	1.1	13.1
1856	1.8	0.3	3.4	0.1	0	0	0	0	0	9.2	6.5	0	21.3
1857	5.3	1.8	1.2	1.1	1.6	0.1	0	0	1.1	2.2	3.2	4.4	22.0
1858	7.1	2.6	0.5	0.2	0	0.1	0	0.3	0.5	2.1	4.9	12.6	30.9
1859	10.1	4.0	2.2	0.7	0.5	0	1.1	0.5	0.5	0	12.8	8.2	40.6
1860	1.7	2.9	2.3	0.5	0.3	0.1	0.1	0	0	2.7	3.1	2.8	16.5
1861	6.4	0	0.5	0.3	0.4	0	0	0	1.5	7.0	2.5	1.6	20.2
1862	0.9	1.1	1.2	4.2	0.9	0	0	0	0	1.7	5.2	1.8	17.0
1863	1.1	2.0	3.7	1.9	0.1	0	0	0	1.4	2.6	5.1	5.9	23.8
1864	6.2	2.1	0.2	0.7	0.4	0	0	0	0.5	4.0	2.8	3.8	20.7
1865	1.5	1.8	0.2	0.1	0	0	0	0	3.6	2.0	2.5	4.6	16.3
1866	0.6	2.1	0.5	0	0.4	0.1	0	0	0	3.1	2.2	0.4	9.4
1867	0.6	0.1	0.8	0.4	0	0	0	1.0	1.3	1.0	3.0	3.2	11.4
1868	3.1	0.6	5.8	2.1	0	0.2	0	0	0.6	5.1	4.4	1.6	23.5
1869	6.1	0.5	2.3	0.6	0	0	0.9	1.0	0	5.53	2.77	3.16	22.86
1870	2.18	2.06	3.19	1.89	0.04	0	0	0	2.23	1.93	0.51	2.49	16.52
1871	5.60	1.09	0.76	0.15	0.15	0	0	1.20	0	2.63	3.73	7.67	22.98
1872	3.48	2.01	0.54	0.88	0	0	0	0.15	0	2.55	2.20	1.94	13.75
1873	1.81	2.91	2.27	1.49	0.82	0	0	0	0.56	2.40	4.87	9.11	26.24
1874	6.91	1.45	6.68	0.21	0.38	0	4.10	0	0	5.12	7.03	2.20	34.08
1875	1.48	3.54	1.37	0.70	0	0	0	0.41	2.72	5.40	2.79	9.69	28.10
1876	2.96	1.68	0.84	1.34	0.09	0.69	0	0	0	4.05	2.79	0.76	15.20
1877	5.41	1.65	1.05	0.33	0	0	0	0	1.11	5.53	3.82	5.01	23.91
1878	2.87	2.01	0.76	0.42	3.55	0	0	0	0	1.37	3.35	2.38	16.71
1879	2.57	0.75	2.20	0.27	1.03	0	0	0	5.21	2.03	4.58	2.44	21.08
1880	3.42	3.20	2.60	0.21	0.50	0	0	0	1.51	2.66	1.87	2.33	18.30
1881	0.48	1.78	0.12	0.65	2.12	0	0	0	0.33	0.99	1.59	7.46	15.52
1882	3.03	2.04	3.30	1.39	0.14	0.11	0	0	0.09	1.53	1.15	5.86	18.64
1883	2.21	3.31	1.80	0.46	0.07	0	0.27	0.18	0.37	3.35	5.73	3.11	20.86
1884	3.17	0.79	2.00	0.26	0.53	0.22	0	0	0.50	1.97	5.65	6.66	21.75
1885	5.19	0.48	0.34	0.18	0	0	0	0.62	0.48	3.17	5.43	4.43	20.32
1886	6.63	5.11	1.17	0.60	0.47	0	0	0	4.50	0.67	4.54	2.73	26.42
1887	2.89	1.46	1.19	0.71	0	0	0	1.25	0.61	11.97	1.05	0.55	21.68
1888	2.36	1.42	0.71	0.03	0.53	0	0	0.06	0.91	2.69	1.97	1.45	12.13
1889	8.15	1.62	2.29	0.43	0.50	0	0	0	1.27	0.29	0.95	9.33	24.83
1890	1.50	4.05	0.73	0.64	0.26	0	0	0	1.28	4.82	2.32	3.57	19.17
1891	3.15	4.10	0	0.42	0.18	0.29	0	0	0.59	2.04	1.63	4.26	16.66
1892	2.85	1.15	0.45	1.71	2.67	0	0.41	0	4.38	2.15	7.18	2.42	25.37
1893	7.00	1.00	1.44	0.84	0	0	0	0	0	3.48	4.07	6.71	24.54
1894	4.65	5.02	1.57	2.35	0	0	0	0	0.26	2.07	5.10	6.19	27.21
1895	1.44	0.89	0.55	0.06	0.59	0	0	0	0	0.70	1.94	2.56	8.73
1896	3.21	2.04	1.56	3.21	0.89	0.08	0	0.02	0.04	2.95	6.45	4.01	24.49
1897	0.51	0.96	0.42	1.89	1.54	0	0	0	0.43	2.24	1.86	2.82	12.67
1898	2.12	2.05	0.64	1.48	0	0	0	0	1.31	8.93	4.17	9.03	29.73
1899	2.15	1.95	0.73	0	0	0	0	0	1.35	0.74	2.66	5.77	15.35
1900	4.91	1.14	1.01	1.84	0.65	0.43	0	0	0	1.76	3.57	0.93	16.24

Year	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Yearly totals
1901	4-32	3-37	0-52	0-53	1-29	0-25	0	0	0	4-61	4-91	0-90	20-70
1902	1-26	1-82	0-85	1-22	0-36	0	0	0	2-61	3-74	8-11	4-43	24-40
1903	3-26	1-61	0-92	0-45	0	0	0	0	1-20	0-23	2-34	3-57	13-58
1904	3-97	0-56	1-01	0	0	0-17	0	0-27	1-89	5-09	3-05	3-04	19-05
1905	2-59	1-70	0-79	0-24	0-33	0	0-95	0	0-82	3-45	0-76	10-83	22-46
1906	5-43	5-84	0	0-71	0-25	0	0	0-88	1-42	7-27	1-99	2-87	26-66
1907	4-24	3-14	2-98	1-04	0	0	0	0-45	2-39	2-96	3-47	1-21	21-88
1908	1-00	2-30	2-84	0-42	0	0	0	0	2-02	0-66	1-99	8-78	20-01
1909	5-38	2-30	1-10	1-87	1-01	0	0	0	0-57	3-46	1-47	3-29	20-45
1910	5-24	3-76	0-99	0-49	0	0	0	0	2-12	0-78	1-88	6-06	21-32
1911	6-69	0-64	1-17	1-60	1-48	0	0	0	1-69	0	9-69	2-80	25-76
1912	4-15	0-68	0-68	1-33	1-37	0	0	0	3-11	0-63	5-25	1-41	18-61
1913	3-40	2-45	0-96	0-98	0-80	0	0	0	0	3-91	1-29	2-09	15-88
1914	4-15	1-67	1-54	0	0	0	0	0	2-17	2-63	4-82	0-90	17-88
1915	1-39	2-89	1-47	2-46	0	0-76	0	0-24	0-66	1-73	4-18	0-73	16-51
1916	4-00	4-39	0-29	1-80	0	0	0	0-23	2-08	0-61	4-93	0-96	19-29
1917	3-10	1-92	1-92	0-43	0	0-46	0	0	0-75	2-85	4-67	3-70	19-80
1918	0-50	1-87	4-56	0-43	0-23	0-18	0	0	0-66	2-66	4-75	3-85	19-69
1919	4-02	2-09	1-14	1-43	0-72	0	0	0	1-15	0-96	4-04	2-79	18-34
1920	0-62	3-02	1-68	0-60	0	0	0	0	0-59	4-32	11-93	1-63	24-39
1921	3-11	1-29	1-63	3-26	0	0	0	0	0-92	0-74	3-61	3-20	17-76
1922	0-76	0-32	0	0-35	0	0	0	0	0	0-85	1-58	5-66	9-52
1923	4-22	4-11	0-88	1-39	0	0	0	0	0	0	2-47	4-36	17-43
1924	3-22	2-26	1-94	1-32	0	0	0	0	0	4-00	1-83	8-50	23-07
1925	1-73	1-42	6-97	0-52	1-64	0	0	0	0-44	6-65	3-81	0-39	23-57
1926	1-83	1-62	2-00	1-69	0-43	0	0	0	1-04	0-23	5-37	2-01	16-22
1927	2-09	2-02	1-35	0-59	0-12	0	0	0	0-27	0-47	3-53	6-91	17-35
1928	7-59	3-13	4-84	1-79	0	0	0	0	2-20	1-91	6-51	4-77	32-74
1929	1-74	3-96	3-08	1-05	0-30	0	0	0	2-63	0-65	4-47	2-41	20-29
1930	4-64	6-10	0-35	1-07	0	0	0-05	0	1-87	3-38	1-49	5-82	24-77
1931	9-42	4-40	0-24	0-12	1-14	0	0	0	0-57	6-74	3-96	4-23	30-83
1932	3-12	6-38	2-04	0-17	0	0	0	0	1-11	5-71	6-15	2-16	26-84
1933	7-16	4-15	0-21	0-09	0-45	0-75	1-34	0-73	0-09	0-14	3-17	4-06	22-34
1934	5-91	1-15	1-31	0-58	1-11	0	0	0	1-81	4-16	6-68	6-78	29-49
1935	5-98	0-81	6-02	0	0	0	0	0	0	0-82	4-74	4-53	22-90
1936	0-90	0-82	0-28	0-94	1-20	0	0	0-98	0-07	1-43	6-79	5-82	19-23
1937	2-00	2-02	0-92	0-25	0-23	0	0	0	1-30	1-81	2-55	4-99	16-07
1938	5-72	7-74	2-10	0-52	0-37	0	0	0-24	0	2-12	5-79	4-31	28-91
1939	1-70	1-99	1-66	3-82	0	0	0	0	8-71	4-73	1-72	1-52	25-85
1940	3-49	0-92	2-35	1-64	0-88	0	0	0	0-19	1-20	2-49	7-36	20-52
1941	1-41	1-19	1-50	1-59	1-48	0	0	0	0-23	1-23	6-16	5-13	19-92
1942	5-47	6-92	0-62	0	0	0	0	0-66	0-08	2-55	5-05	7-89	29-24
1943	1-94	2-39	6-11	0-17	0-82	0-57	0	0	0	4-12	3-93	2-29	22-34
1944	3-06	2-17	2-55	1-67	0	0	0	1-76	2-29	1-22	2-01	9-09	25-82
1945	2-47	1-01	0-99	0-65	0-18	0	0	0	0-45	1-07	4-97	2-66	14-45
1946	4-47	0-84	1-46	0-33	0-06	0	0	0	0-17	2-39	3-26	6-58	19-56
1947	2-16	0-31	0-05	0-10	0	0	0	0-20	0-19	1-28	0-75	2-80	7-84
1948	0-80	1-62	0-31	0-48	0-02	0-07	0	0	0-04	4-50	4-71	7-74	20-29
1949	1-52	3-03	1-41	0-31	0-68	0-08	0	1-98	0	7-96	5-13	1-17	23-27
1950	5-36	2-49	3-55	0-92	0	0	0	0	0	5-95	0-65	4-54	23-46
1951	2-99	1-20	1-27	0-06	0-23	0	0	0-39	5-10	14-93	2-66	1-85	30-68
1952	2-70	1-65	0-63	0-32	0-29	0	0	0	0-37	1-33	3-25	4-63	15-17
1953	6-36	0-72	6-09	1-42	1-07	0-89	0	0-83	0-27	3-87	5-45	1-64	28-61

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