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Met O 3 Technical Note No. 13

Changes in the Seasonal Variation of Temperature over the United Kingdom between 1861 and 1980

by

S. G. Smith (Met O 3)

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Changes in the Seasonal Variation of Temperature over the United Kingdom between 1861 and 1980

1. Introduction

The Climatological Research Group in the Climatological Services Branch were recently asked to give advice relating to the variation of temperature through the winter months. In the course of answering this enquiry, it was found that thirty year means of daily temperatures failed to remove irregular day-to-day variations in the temperatures. The means also produced apparent warm or cold spells of several days duration which are, in general, purely a function of the particular period chosen. These features are illustrated in fig 1, which is a plot of mean daily maximum temperatures at Oxford for January 1st to February 17th over the periods 1901-30 and 1941-70.

Harmonic analysis of the data was therefore carried out (described below) to smooth out the "noise" and this was considered to lead to a more satisfactory description of the seasonal variation than the raw thirty year means. The differences that can occur in the seasonal variation were also investigated for various thirty year periods.

The harmonic analysis was performed firstly on daily maximum and daily minimum temperatures from five UK stations using data for 1901-30 and 1941-70. The procedure was then repeated on Oxford data only for ten overlapping thirty year means between 1861 and 1980, the results of which are assumed to be applicable to the other four stations.

2. Previous work

Craddock (1956a) investigated the amplitude and phase of the first and second annual harmonics of monthly mean temperatures at 160 stations in the British Isles, using data for 1921-50. In a related paper (1956b) he fitted two term annual harmonics to non-overlapping five day means of daily temperatures at 42 stations in central and northern Europe. In both papers his primary interest was to determine the spatial patterns in the parameters, in particular relating variations in the phase of the second harmonic to changes in the seasonal variation of temperature. In this paper priority is given to studying changes with time of the harmonics. Also, maximum and minimum temperatures are treated separately and daily rather than five day or monthly means are employed.

3. Data

Five widely scattered stations having almost unbroken daily maximum and minimum temperatures between 1900 and 1970 were selected for the first part of the analysis. These five are Plymouth, Oxford, Armagh, Durham and Gordon Castle and their locations - marked with their initial letter - are shown in each of figs 2 to 5. Minimum temperatures for Gordon Castle are missing in October 1956 and are therefore excluded. Temperatures are available for Oxford since 1853 and data for 1861 onwards have been used for the second part of the analysis.

With regard to the homogeneity of the observations, Smith (1978) found evidence for changes in the mean of the Plymouth maxima and minima series which may be due to the change of site between the Hoe and Mountbatten in 1930. There is also a possibility that the series for the other stations are not entirely homogeneous due to minor changes of site and/or changes in observing hour. However, since the main purpose of this study is to investigate changes in the variation of temperature within a year these potential inconsistencies should not seriously affect the analysis.

4. Method of analysis

Future reference to "maxima" and "minima" will denote the highest and lowest daily values. "Peak value" will refer to the highest temperature attained by an harmonic in the regression model described below.

For each 30 year period and for each station, maxima and minima were averaged separately for each day of the year. February 29th was omitted and so each series comprised 365 terms. Each term y_t was assumed to follow an expression of the form

$$y_t = \bar{y} + \sum_{i=1}^{N} (a_i \cos ict + b_i \sin ict)$$

where $\bar{y}$ is the mean,

a_i, b_i are the components of the i^{th} annual harmonic (up to i = N)

$$c = \frac{2\pi}{365}$$

and t is measured in days from midnight on December 31st.

It was found that the first two harmonics accounted for over 95% of the variance of both the maxima and minima series and higher order harmonics were therefore neglected.

The components of the first two harmonics were estimated using a least squares regression program available in the BMDP statistical package (Dixon and Brown (1979)). The amplitudes A_i and phases ϕ_i were calculated from the components, where

$$A_i = (a_i^2 + b_i^2)^{\frac{1}{2}}$$

$$\phi_i = \tan^{-1}\left(\frac{b_i}{a_i}\right)$$

The date of peak value of the first harmonic and the date of summer peak value of the second harmonic were determined from ϕ.

5. Results

Results are presented in two sub-sections. Section 5.1 relates to analyses for the five stations over 1901-30 and 1941-70. Section 5.2 considers Oxford data only for the longer period 1861-1980.

5.1 Five stations

Table 1 presents means and variances of the y_t values together with the highest and lowest value of y_t and their dates of occurrence. For both maxima and minima, the 1941-70 means are about 0.3°C higher than 1901-30 means, the exception being for Plymouth maxima (which may be due to the effects of site change). The general increase occurs despite the fact that January and February temperatures are lower in the 1941-70 period. The variances are also higher in the later period. This result is mainly a reflection of the fact that there is a greater annual range of daily temperature for 1941-70, as implied by the highest and lowest values given in Table 1. For these values, their dates of occurrence fluctuate considerably and therefore have limited usefulness.

Figs 2 to 5 show, for the first harmonic in 1941-70, the variation across the country of the amplitude and of the date of peak value for maxima (figs 2 and 3) and for minima (figs 4 and 5). The isopleths are based on the pattern of variation observed by Craddock (1956a) but it would be unwise to infer parameter values from figs 2-5 alone.

The differences in the amplitude and phase between the five stations agree with Craddock's results and will not be discussed here. Comparing fig 2 and fig 4 it is seen that the amplitude for maxima is 20-30% greater than for minima. The date of peak value for maxima (fig 3) occurs 8-11 days earlier than for minima (fig 5). The result for the amplitudes is a measure of the greater annual range of maxima; that for the dates of peak value probably arises from the fact that

i. maxima are highly related to the amount of solar radiation received at the earth's surface and the maximum and minimum elevation of the sun occurs in June and December respectively.

ii. minima are governed more by the atmospheric dew point which in turn is related, amongst other factors, to the earth and sea temperatures which reach their maximum and minimum after the solstices.

Table 2 gives results for the components, amplitudes and phases of the first harmonic for the two periods. The standard errors of the amplitude and phase have been derived from the standard errors of the components supplied by the BMDP regression program. That of the amplitude was found to be approximately 0.04°C and that of the date of peak value 0.4 days, with the latter inversely proportional to the amplitude. The variance of the amplitude is given by $A^2/2$ where A is the amplitude. In the table this variance is expressed as a proportion of the variance of the series. It equals about 98% of the total for maxima and only slightly less for minima. This proportion increases slightly between 1901-30 and 1941-70 for maxima (except at Gordon Castle) and more substantially for minima. The peak value date for both variables remains fairly constant, the only appreciable change occurring for Plymouth minima.

Table 3 presents statistics for the second harmonics. The standard error of the amplitude is again about 0.04°C but the date of peak value approximately 2 days, with its magnitude inversely proportional to the amplitude. The variance explained for maxima is less than 1% of the total and shows a decrease from 1901-30 and 1941-70. For minima the amount explained is about 3.5% in 1901-30 but drops to below 1% in 1941-70. The phase of the second harmonic has also altered considerably, particularly for maxima. The date of peak value for maxima occurs about one month later in the 1941-70 period and 11 days later for minima, compared to 1901-30. These findings are discussed in Section 6.

5.2 Oxford only

To relate changes in the magnitude and phase of the harmonics between 1901-30 and 1941-70 to other periods the analysis of 5.1 was repeated for the periods 1861-1890, 1871-1900, ... 1951-80 for Oxford data. The results of the previous sub-section showed little deviation from station to station in regard to the differences between 1901-30 and 1941-70. It is therefore assumed that results for Oxford presented below can be considered representative of the other four stations and indeed of the UK as a whole.

Various statistics are presented for the different periods in Table 4. For maxima, the mean and highest and lowest values increase between 1881-1910 and 1921-50 followed by a decline. The variance reaches its maximum in 1941-70. For minima, the mean increases monotonically after 1881-1910 but for the other statistics the variations with time are more complex.

Table 5 gives results for the first harmonic. The proportion of variance and the phase for maxima are relatively constant although some differences emerge for the most recent periods. For minima the phase is constant but the proportion of variance decreases until 1901-30 then increases.

Turning to the results for the second harmonic (Table 6), for maxima the proportion of variance is highest in 1921-50 and has fallen since then. The date of peak value is earliest in 1901-30 and latest in 1941-70, the two periods considered in 5.1. For minimum, these same two periods almost yield the two extremes for the proportion of variance and the date of peak value.

6. Interpretation of results

It has been shown that between 1861-90 and 1951-80 some large differences occurred in the proportion P_1 of the variance accounted for by the first harmonic and the corresponding quantity P_2 and date of peak value D_2 for the second harmonic. A period in which P_1 is relatively large and P_2 relatively small (for example 1941-70) has, on average, a seasonal variation in temperature more closely resembling a pure sine curve than a period for which the reverse is true e.g. 1901-30. If D_2 is later in the year for one period than another (up to a maximum of 45 days later), as it is in 1941-70 relative to 1901-30, then this implies the winter is more pronounced and the summer extends later into the year, with a consequent decrease in length of the autumn season. These effects are displayed diagrammatically in Craddock (1956a).

It was decided to study the results in quantitative terms by comparing, for the period 1901-30 and 1941-70, plots of daily values through the year generated from their respective means and first two harmonics. These periods were chosen because in general they give the most extreme results, in opposite senses, for the phases and magnitudes of the harmonics. Plots for maxima are given in fig 6; not that only values every fifth day are shown. It is observed that the features discussed above can be identified and that the maximum difference between the two curves is just under 1°C (in the autumn). The same is true for minima (fig 7) but the differences are more pronounced with the greatest discrepancy between the two curves about 1°C, again occurring in the autumn. However it is noted from Table 4 that the mean temperature difference (1941-70 minus 1901-30) is 0.2°C for maxima and 0.3°C for minima. If one therefore considers the differences in the seasonal variation with these mean differences removed, the maximum difference takes place in mid-winter, equally about 0.8°C for maxima and 1.0°C for minima.

7. Conclusion

Harmonic analysis of UK daily maximum and minimum temperatures averaged over different thirty year periods has shown some statistically significant differences in the amplitude of the first harmonic and amplitude and phase of the second harmonic. Comparing results for the period 1901-30 and 1941-70, the effect has been observed to give a shorter but sharper winter for the latter period, a summer which extends later into the year and a shorter autumn. In terms of temperatures, if differences in the annual mean are removed, the greatest difference in the seasonal variation occurs in mid-winter where 1941-70 averages are about 0.8-1.0°C less than 1901-30 values.

8. References

Craddock, J. M. 1956a The harmonic representation of the annual temperature variation in different parts of the British Isles.
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Craddock, J. M. 1956b The representation of the annual temperature variation over central and northern Europe by a two-term harmonic form.
Q.J.R. Met. S., 82, No. 353, pp 275-288.

Dixon, W.J. and Brown, M. B. 1979 Biomedical Computer Programs, P-Series. Univ. of California Press. Program used BMDP1R, revision date Nov. 1979. Programs were developed at Health Sciences Computing Facility (HSCF), UCLA. The HSCF was sponsored by NIH Special Resources Grant RR-3.

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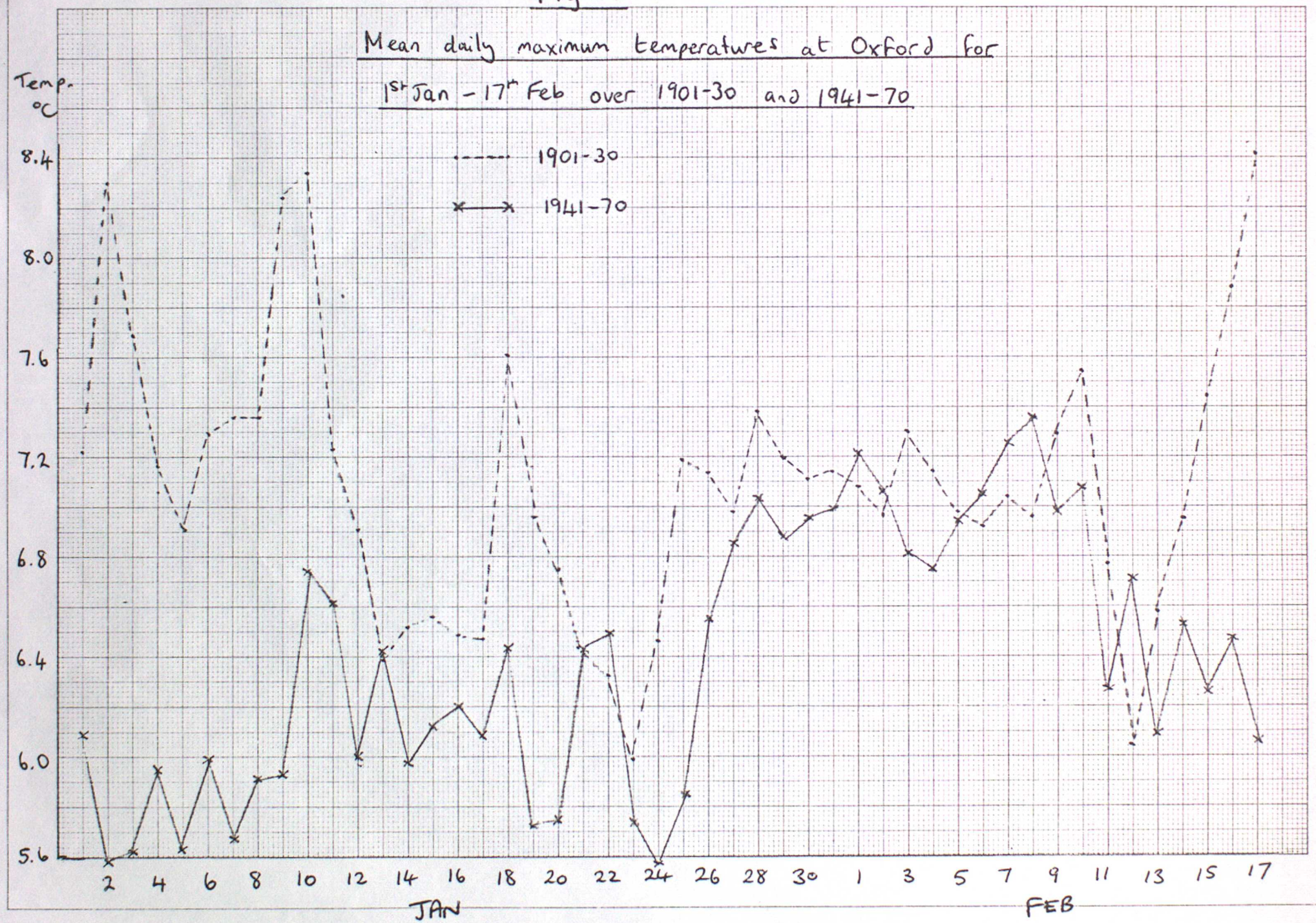
Fig 1

Mean daily maximum temperatures at Oxford for 1st Jan – 17th Feb over 1901-30 and 1941-70



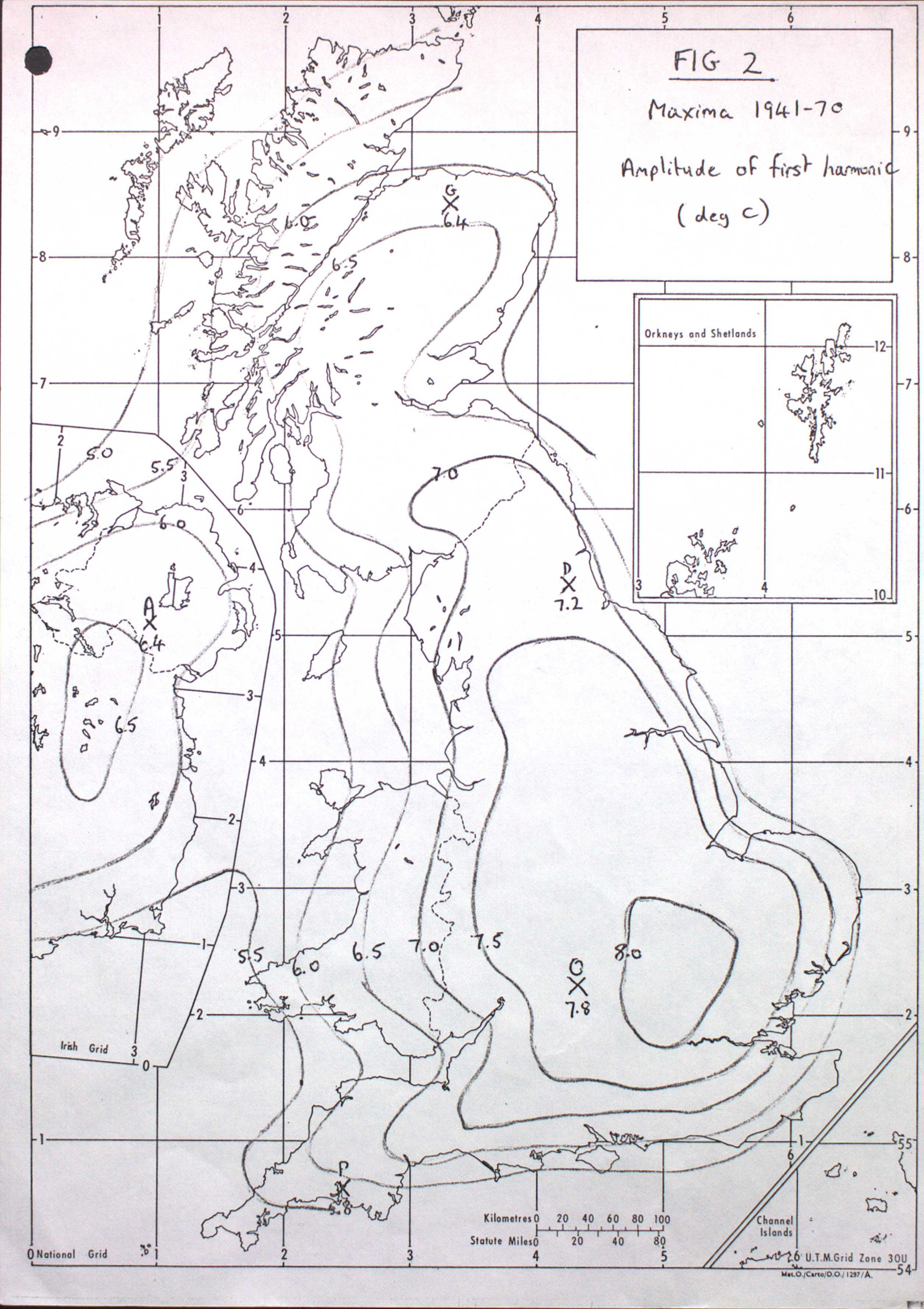


FIG 2
Maxima 1941-70
Amplitude of first harmonic
(deg C)
Orkneys and Shetlands
G
6.4
D
7.2
A
6.4
O
7.8
P
6.0
6.5
7.0
5.5
5.0
7.5
8.0
Irish Grid
National Grid
Kilometres 0 20 40 60 80 100
Statute Miles 0 20 40 80
Channel Islands
U.T.M. Grid Zone 30U
Met.O./Carto/D.O./1297/A.

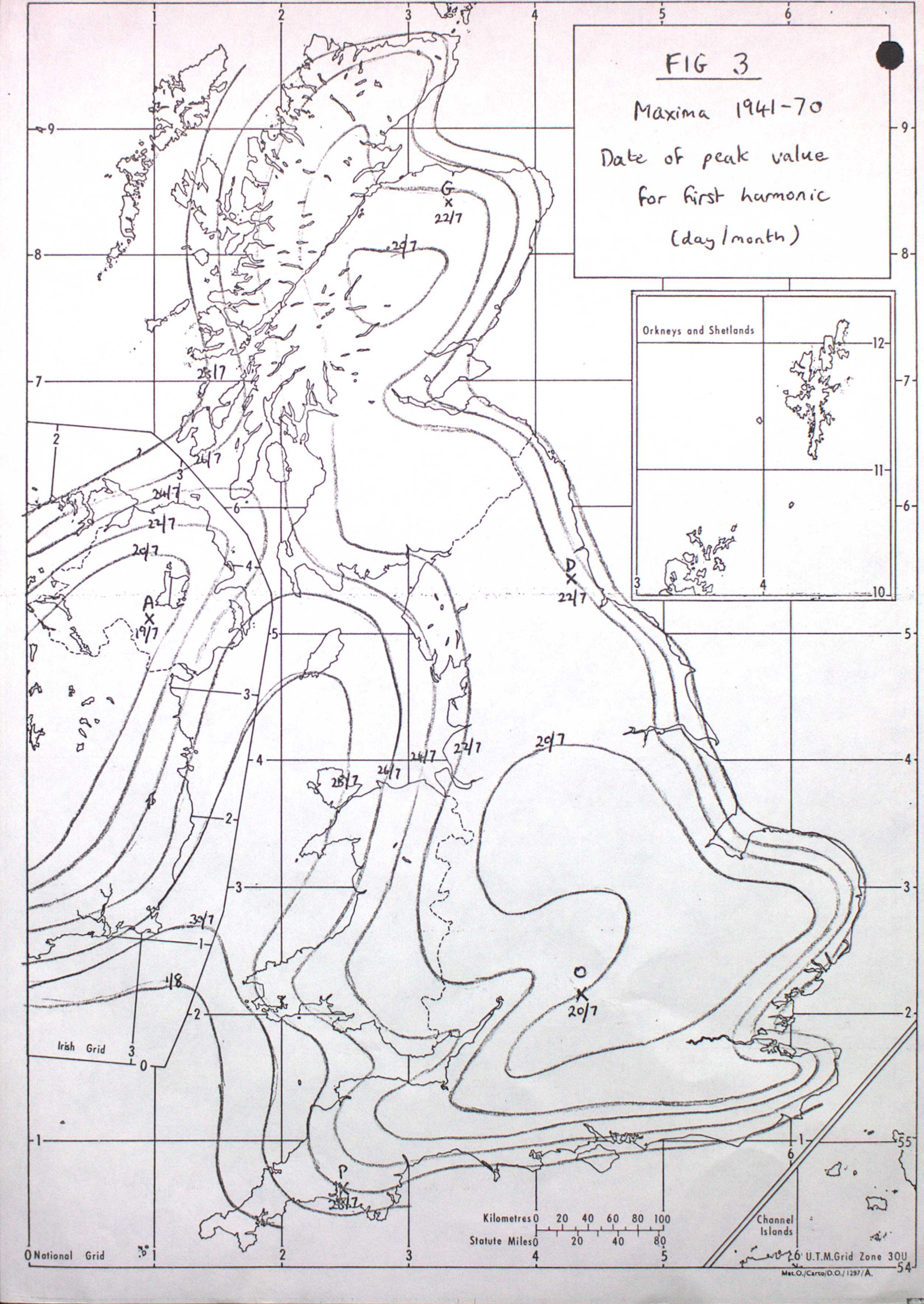


FIG 3
Maxima 1941-70
Date of peak value
for first harmonic
(day/month)
Orkneys and Shetlands
G
22/7
29/7
25/7
26/7
24/7
22/7
20/7
A
19/7
D
22/7
24/7
22/7
20/7
28/7
26/7
30/7
1/8
O
20/7
P
28/7
Irish Grid
National Grid
Kilometres 0 20 40 60 80 100
Statute Miles 0 20 40 80
Channel Islands
U.T.M. Grid Zone 30U
Met.O./Carto/D.O./1297/A.

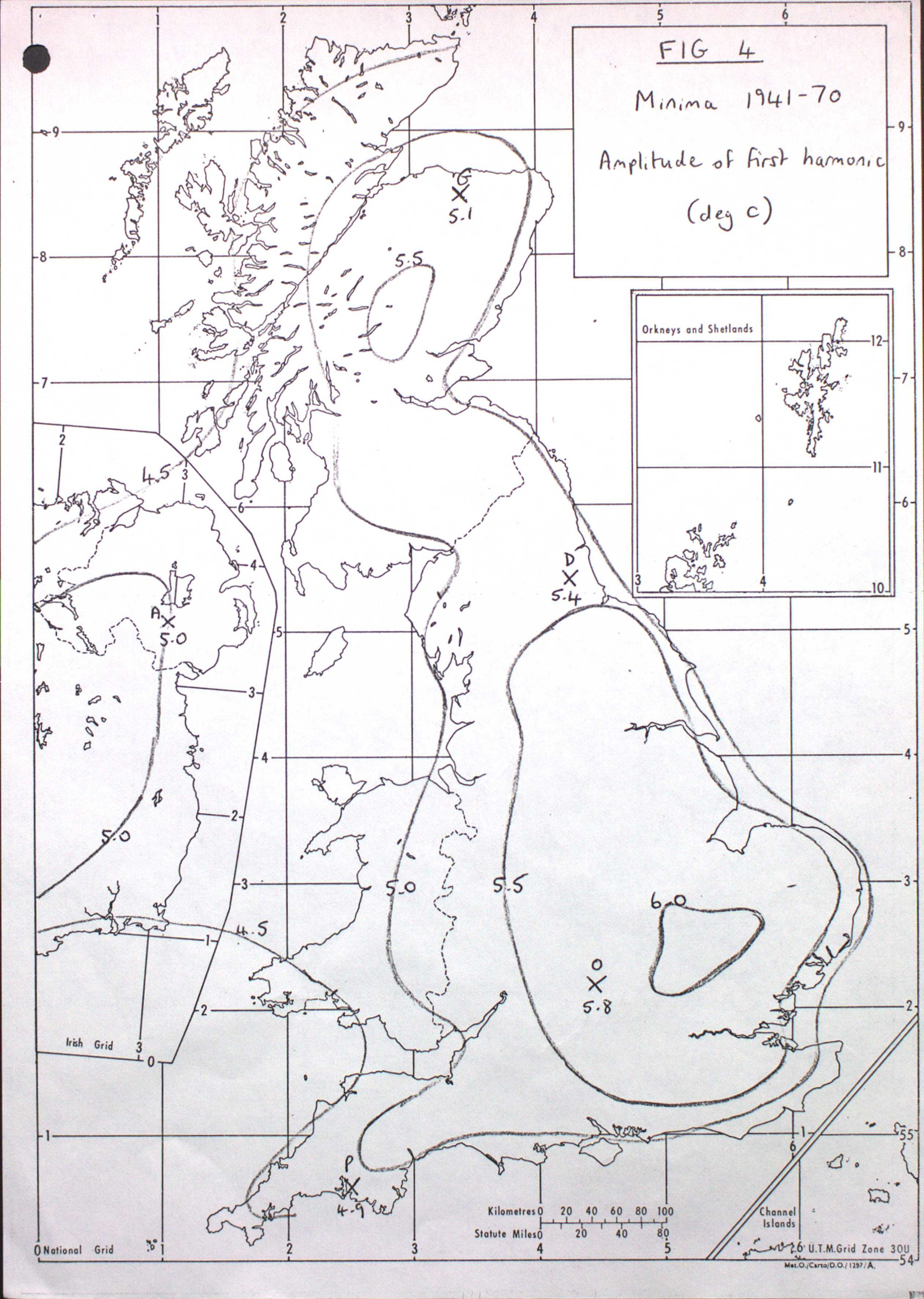


FIG 4
Minima 1941-70
Amplitude of first harmonic
(deg c)
Orkneys and Shetlands
G
5.1
5.5
D
5.4
A
5.0
4.5
5.0
5.0
5.5
6.0
O
5.8
P
4.9
Irish Grid
Kilometres 0 20 40 60 80 100
Statute Miles 0 20 40 80
Channel Islands
National Grid
U.T.M. Grid Zone 30U
Met.O./Carto/D.O./1297/A.

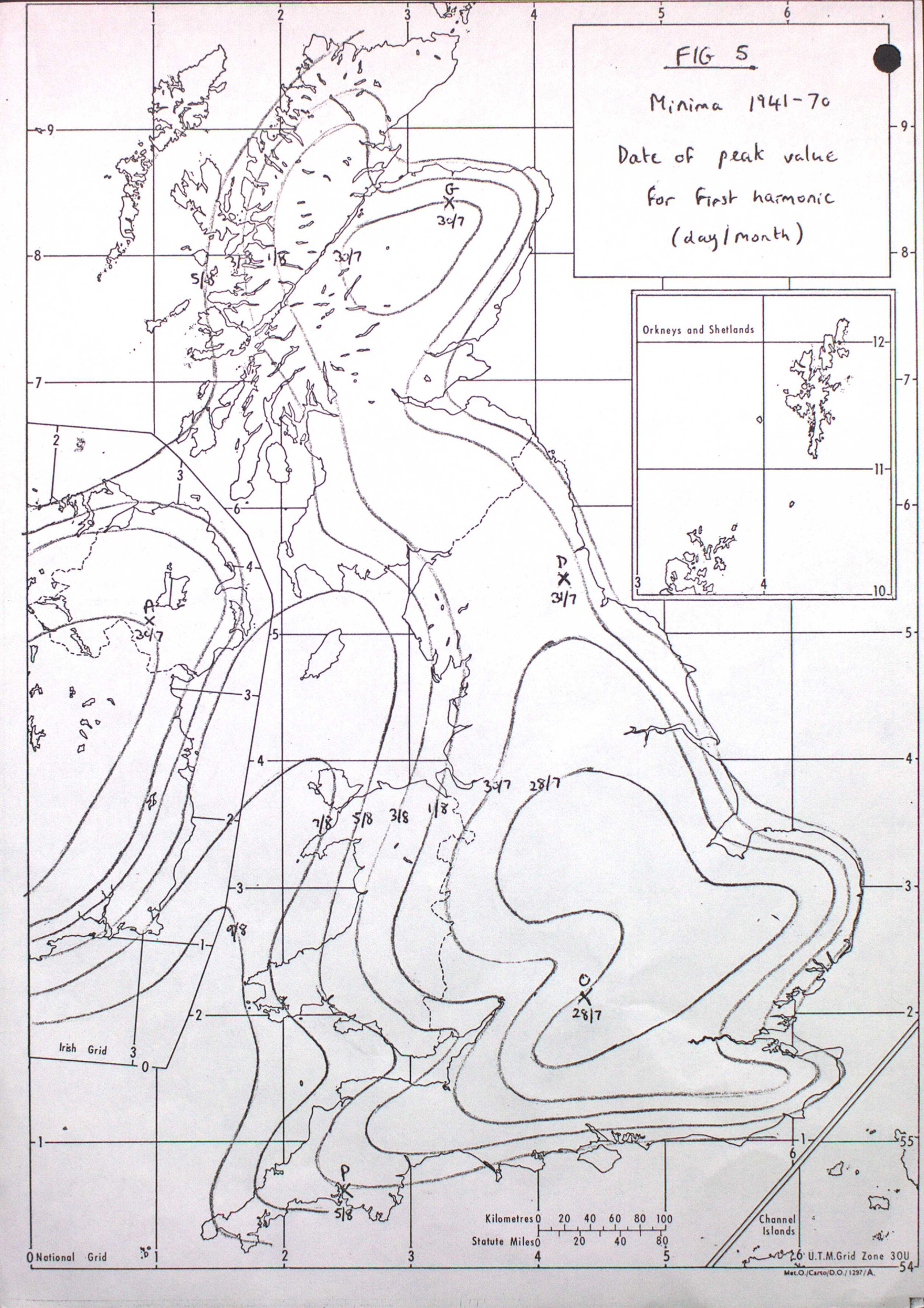


FIG 5
Minima 1941-70
Date of peak value
for First harmonic
(day/month)
Orkneys and Shetlands
G
34/7
A
34/7
D
31/7
C
28/7
P
5/8
34/7
28/7
7/8
5/8
3/8
1/8
9/8
Irish Grid
National Grid
Kilometres 0 20 40 60 80 100
Statute Miles 0 20 40 80
Channel Islands
U.T.M. Grid Zone 30U
Met.O./Carto/D.O./1297/A.

Fig 6

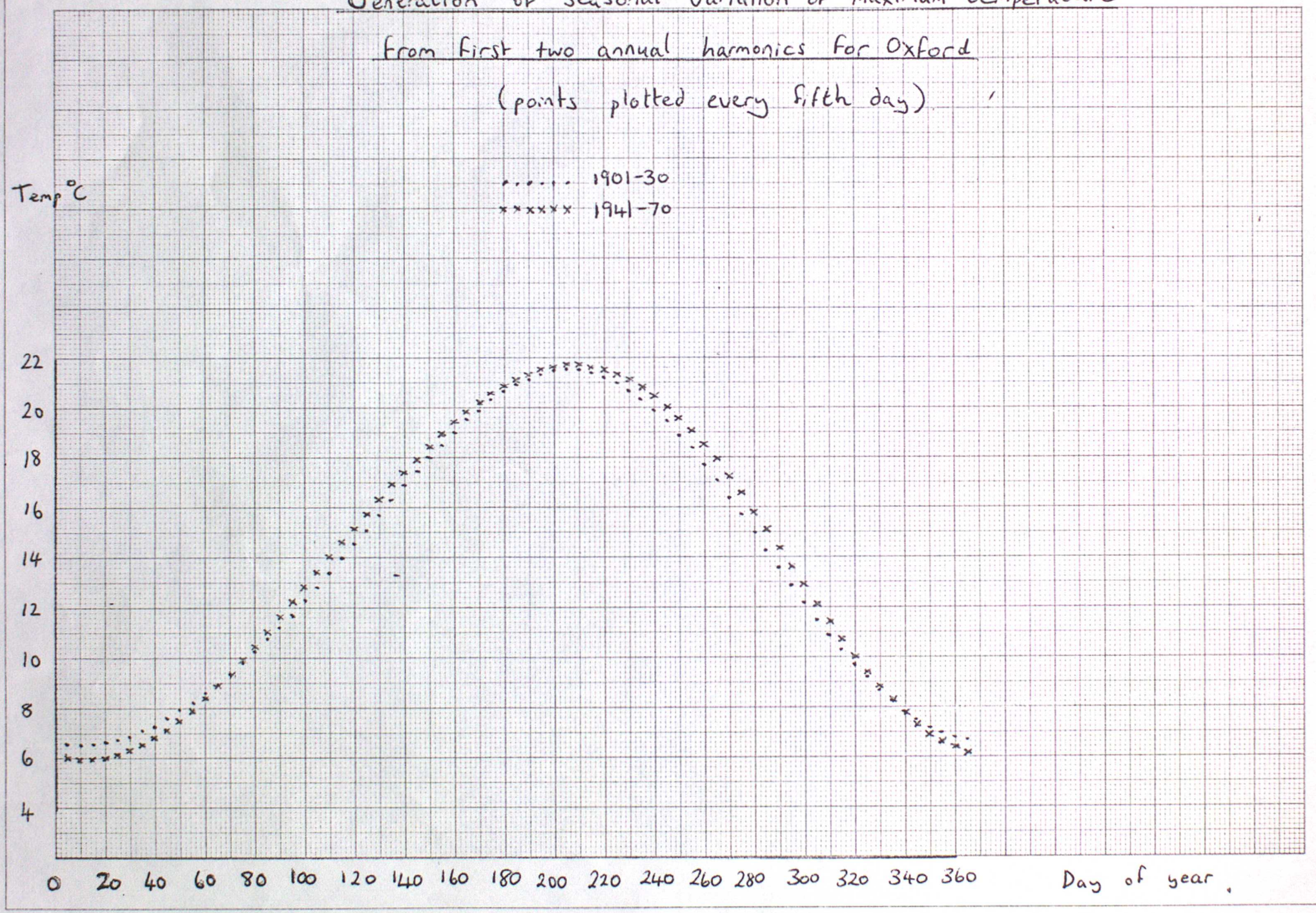

Generation of seasonal variation of maximum temperature
from first two annual harmonics for Oxford
(points plotted every fifth day)
Temp °C
..... 1901-30
xxxxxx 1941-70
22
20
18
16
14
12
10
8
6
4
0 20 40 60 80 100 120 140 160 180 200 220 240 260 280 300 320 340 360
Day of year

Fig 7

Generation of seasonal variation of minimum temperatures

From first two annual harmonics for Oxford

(points plotted every fifth day)

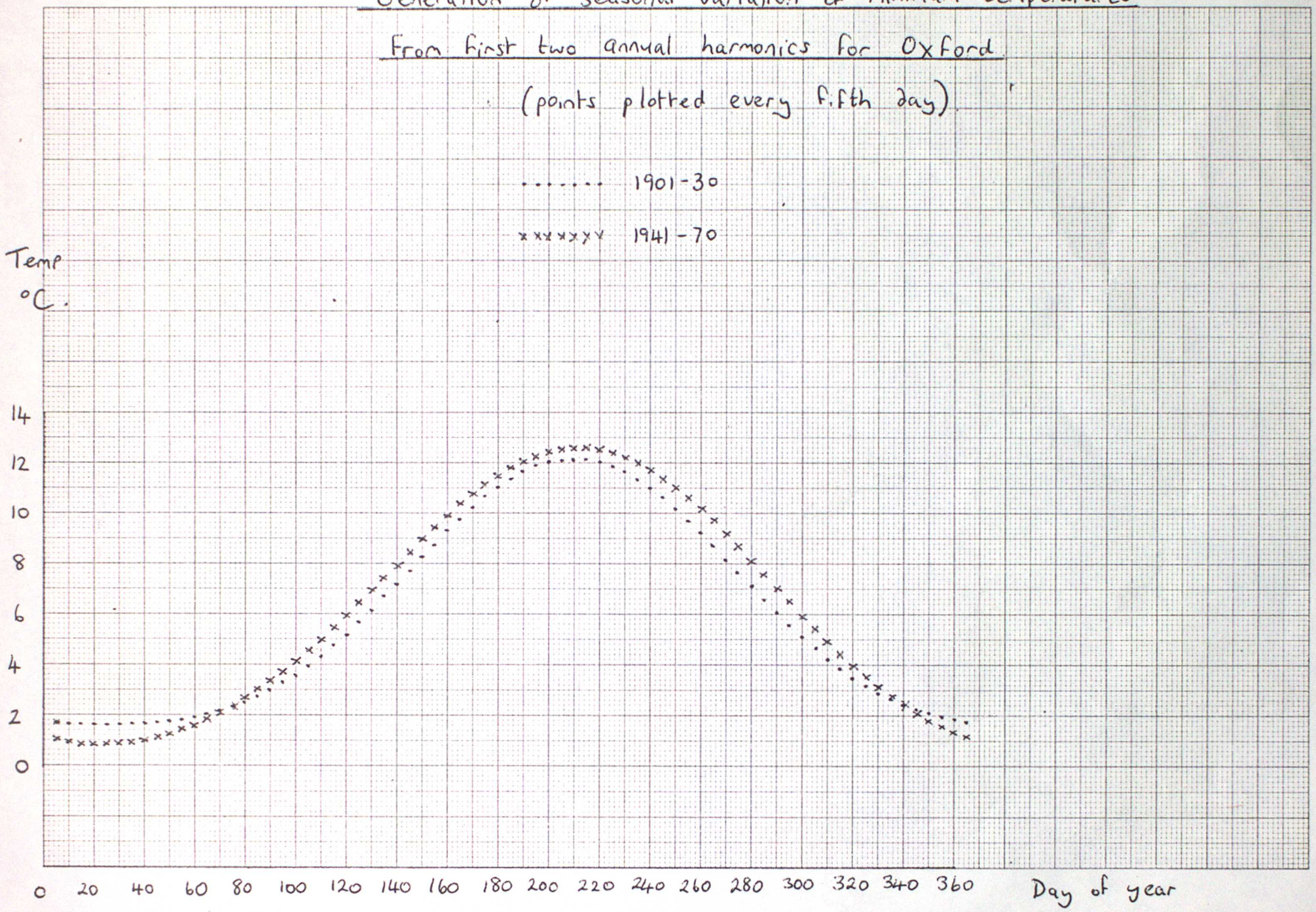


TABLE 1

Summary data for each station and period

(i) Maxima

		Mean (deg c)	Variance (deg c)^2	Highest Value	Highest Date	Lowest Value	Lowest Date
Oxford	1901-30	13.68	28.14	23.4	12 Jul	6.0	23 Jan
	1941-70	13.89	31.14	22.9	25 Jul	5.6	24 Jan
Plymouth	1901-30	13.76	16.81	20.7	14 Aug	8.1	14 Jan
	1941-70	13.48	17.00	20.0	1 Jul	6.9	19 Feb
Armagh	1901-30	12.60	18.97	19.9	14 Jul	6.3	13 Jan
	1941-70	13.04	20.69	20.0	31 Jul	6.2	4 Jan
Durham	1901-30	11.85	23.43	20.4	14 Jul	4.9	12 Jan
	1941-70	12.38	26.22	20.8	25 Jul	4.7	24 Jan
Gordon Castle	1901-30	11.87	19.79	19.7	14 Jul	5.1	29 Dec
	1941-70	12.07	21.41	19.4	25 Jul	5.1	10 Jan

(ii) Minima

Oxford	1901-30	5.96	14.73	13.1	22 Jul	0.2	12 Feb
	1941-70	6.28	17.44	13.3	21 Jul	0.3	29 Dec
Plymouth	1901-30	7.66	12.09	13.9	14 Aug	2.1	12 Feb
	1941-70	7.89	12.20	13.7	26 Jul	2.2	18 Feb
Armagh	1901-30	5.39	11.22	11.7	22 Jul	0.3	12 Feb
	1941-70	5.68	12.77	11.9	24 Jul	0.2	14 Jan
Durham	1901-30	4.50	13.67	11.4	14 Aug	-1.1	13 Jan
	1941-70	4.83	15.13	11.3	26 Jul	-1.4	4 Jan
Gordon Castle	1901-30	4.45	11.42	10.6	22 Jul	-0.2	12 Jan
	1941-70	4.82	13.41	11.3	30 Jul	-1.3	20 Jan

TABLE 2

Statistics for the first harmonic

(Five stations)

(i) Maxima

Station and period		Components		Amplitude		Phase
		sin	cos	Value	Variance as % of total	Date of peak value (day/month)
Oxford	1901-30	-2.27	-7.06	7.42	97.8	19/7
	1941-70	-2.49	-7.41	7.82	98.2	20/7
Plymouth	1901-30	-2.44	-5.19	5.73	97.6	27/7
	1941-70	-2.58	-5.17	5.78	98.2	28/7
Armagh	1901-30	-1.92	-5.78	6.09	97.7	20/7
	1941-70	-1.93	-6.08	6.38	98.4	19/7
Durham	1901-30	-2.41	-6.31	6.76	97.5	22/7
	1941-70	-2.55	-6.70	7.17	98.1	22/7
Gordon Castle	1901-30	-2.17	-5.80	6.20	97.1	22/7
	1941-70	-2.29	-6.03	6.43	96.5	22/7

(ii) Minima

Oxford	1901-30	-2.35	-4.72	5.27	94.3	28/7
	1941-70	-2.64	-5.19	5.82	97.2	28/7
Plymouth	1901-30	-2.45	-4.11	4.78	94.5	1/8
	1941-70	-2.71	-4.03	4.86	96.8	5/8
Armagh	1901-30	-2.22	-3.98	4.56	92.5	31/7
	1941-70	-2.38	-4.35	4.96	96.2	30/7
Durham	1901-30	-2.49	-4.42	5.07	94.0	31/7
	1941-70	-2.70	-4.72	5.43	97.4	31/7
Gordon Castle	1901-30	-2.16	-4.10	4.64	94.3	29/7
	1941-70	-2.42	-4.50	5.11	97.3	30/7

TABLE 3

Statistics for the second harmonic

(Five stations)

(i) Maxima

Station and period		Components		Amplitude		Phase
		sin	cos	Value	variance as % of total	Date of summer peak (day/month)
Oxford	1901-30	0.54	0.06	0.55	0.5	13/8
	1941-70	0.30	-0.32	0.43	0.3	8/9
Plymouth	1901-30	0.46	0.07	0.47	0.7	11/8
	1941-70	0.19	-0.14	0.24	0.2	2/9
Armagh	1901-30	0.52	0.14	0.54	0.8	8/8
	1941-70	0.24	-0.26	0.36	0.3	8/9
Durham	1901-30	0.61	0.18	0.63	0.8	8/8
	1941-70	0.33	-0.27	0.43	0.4	4/9
Gordon castle	1901-30	0.54	0.12	0.55	0.8	9/8
	1941-70	0.30	-0.28	0.41	0.4	6/9

(ii) Minima

Oxford	1901-30	0.77	0.54	0.94	3.0	29/7
	1941-70	0.48	0.16	0.50	0.7	7/8
Plymouth	1901-30	0.66	0.49	0.82	2.8	28/7
	1941-70	0.31	0.13	0.34	0.5	5/8
Armagh	1901-30	0.77	0.61	0.98	4.3	27/7
	1941-70	0.47	0.06	0.48	0.9	12/8
Durham	1901-30	0.85	0.47	0.97	3.4	1/8
	1941-70	0.41	0.07	0.42	0.6	11/8
Gordon Castle	1901-30	0.69	0.57	0.89	3.5	27/7
	1941-70	0.38	0.08	0.39	0.6	9/8

TABLE 4

Summary data for Oxford, ten periods.

(i) Maxima

Period	Mean	Variance	Highest	Lowest
1861-90	13.57	31.87	22.8	5.2
1871-1900	13.51	31.06	22.3	4.9
1881-1910	13.46	29.80	21.9	5.0
1891-1920	13.63	29.32	22.6	5.4
1901-30	13.69	28.14	23.4	6.0
1911-40	13.92	29.03	23.2	5.8
1921-50	14.12	30.32	23.5	6.0
1931-60	14.10	31.07	22.9	5.5
1941-70	13.89	31.14	22.9	5.6
1951-80	13.73	29.78	22.3	5.2

(ii) Minima

Period	Mean	Variance	Highest	Lowest
1861-90	5.83	15.65	13.0	-0.1
1871-1900	5.78	16.25	12.8	-0.1
1881-1910	5.77	15.88	12.6	-0.2
1891-1920	5.91	15.23	13.1	0.5
1901-30	5.96	14.73	13.1	0.2
1911-40	6.04	15.37	13.1	0.1
1921-50	6.12	16.79	13.3	0.3
1931-60	6.21	17.51	13.2	0.4
1941-70	6.26	17.64	13.3	0.3
1951-80	6.29	16.71	13.0	0.0

TABLE 5

Statistics for the first harmonic

(Oxford, ten periods)

(i) Maxima

Period	Components		Amplitude		Phase
	sin	cos	Value	variance as % of total	Date of peak value (day/month)
1861-90	-2.36	-7.58	7.91	98.1	18/7
1871-1900	-2.25	-7.47	7.79	97.8	18/7
1881-1910	-2.30	-7.30	7.65	98.3	19/7
1891-1920	-2.24	-7.25	7.59	98.3	18/7
1901-30	-2.27	-7.06	7.42	97.8	19/7
1911-40	-2.30	-7.17	7.53	97.7	19/7
1921-50	-2.36	-7.33	7.70	97.8	19/7
1931-60	-2.44	-7.42	7.81	97.9	19/7
1941-70	-2.49	-7.42	7.82	98.2	20/7
1951-80	-2.63	-7.19	7.66	98.5	21/7

(ii) Minima

1861-90	-2.32	-4.93	5.45	94.7	27/7
1871-1900	-2.49	-4.97	5.56	95.2	28/7
1881-1910	-2.55	-4.90	5.52	96.1	29/7
1891-1920	-2.46	-4.80	5.40	95.7	28/7
1901-30	-2.35	-4.72	5.28	94.5	28/7
1911-40	-2.36	-4.87	5.41	95.1	27/7
1921-50	-2.54	-5.07	5.67	95.8	28/7
1931-60	-2.65	-5.19	5.82	96.8	28/7
1941-70	-2.67	-5.23	5.87	97.5	28/7
1951-80	-2.63	-5.05	5.70	97.1	29/7

TABLE 6

Statistics for the second harmonic

(Oxford, ten periods)

(i) Maxima

Period	Components		Amplitude		Phase
	Sin	Cos	Value	variance as % of total	Date of peak value (day/month)
1861-90	0.66	0.04	0.66	0.7	15/8
1871-1900	0.72	-0.05	0.72	0.8	17/8
1881-1910	0.54	-0.08	0.55	0.5	20/8
1891-1920	0.47	-0.01	0.47	0.4	16/8
1901-30	0.54	0.06	0.54	0.5	13/8
1911-40	0.61	0.05	0.61	0.6	14/8
1921-50	0.66	-0.02	0.68	0.8	16/8
1931-60	0.49	-0.21	0.53	0.5	27/8
1941-70	0.30	-0.32	0.44	0.3	8/9
1951-80	0.38	-0.09	0.39	0.3	22/8

(ii) Minima.

1861-90	0.82	0.39	0.82	2.6	3/8
1871-1900	0.79	0.49	0.93	2.7	30/7
1881-1910	0.60	0.51	0.79	1.9	26/7
1891-1920	0.65	0.55	0.85	2.4	26/7
1901-30	0.77	0.54	0.94	3.0	29/7
1911-40	0.72	0.55	0.91	2.7	28/7
1921-50	0.68	0.39	0.78	1.8	31/7
1931-60	0.50	0.35	0.61	1.1	29/7
1941-70	0.44	0.15	0.47	0.6	6/8
1951-80	0.49	0.24	0.54	0.9	2/8