METEOROLOGICAL SERVICE

AGROMETEOROLOGICAL MEMORANDUM No. 7

EARTH TEMPERATURES IN IRELAND

By
D. L. Fitzgerald, B.Sc.

U.D.C.
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EARTH TEMPERATURES IN IRELAND 1956-'75.

Earth temperatures are measured at depths of 30 cm. (1ft.), 60 cm. (2ft.) and 120 cm (4ft.) under a level unshaded surface covered with short grass. Mercury-in-glass thermometers are used. These are suspended inside a metal tube so that the bulb is at the required depth. The bulb is embedded in wax and takes about ½ hour to assume the temperature of its surroundings; hence, in the period taken to make an observation, the change in temperature is very small. Conduction and convection of heat inside the metal tube cause the thermometer to read too high in summer. At 120 cm. the error is small but at 30 cm. the reading may be about 0.5°C too high on a hot summer day [ref. (1)]. No allowance is made for this error.

Earth temperatures are measured once daily at 0900 G.M.T. This is quite adequate for the 60 cm. and 120 cm. depths where the diurnal variation of temperature is small. At the 30 cm. level the diurnal temperature variation in summer may exceed 2°C. A single reading is less representative and may not be regarded as a mean value. For a midland site an addition of the order of 0.5°C is needed on average to convert the 0900 G.M.T. reading at 30 cm. into a daily mean value. Since the methods used in estimating this correction were crude it was <u>not</u> applied to the 30cm. data used in this publication.

Routine measurements of 5, 10 and 20 cm. soil temperatures and of earth temperatures have been made at all Meteorological Service stations since late 1953. Soil temperatures have been treated in Agrometeorological Memorandum No. 3 and the same methods of tabulation are used here. A mean value of the temperature is given for each month and also a mean annual value. The scatter of the values about the mean is measured by the standard deviation. The highest and lowest values recorded are included to give the range recorded at each depth.

The period needed to give a stable frequency distribution was estimated by calculating the mean, the standard deviation and the range at three long-term stations for periods of 10, 13, 15, 20, 25 and where possible 30 years. It was found that a 10-year record was inadequate but 13 years or more gave similar values of the three parameters in most cases. Details are given in Appendix (A). It was decided to use only those stations whose period of record was at least 13 years. No adjustment to the statistics of stations whose record did not span the full twenty years was considered necessary. The adequacy of the 13-year period enables us to use several climatological stations for which readings at 30 cm. and 120 cm. are

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available. A map of the stations used precedes the tables.

Earth temperatures are influenced by factors of two kinds:

(a) Intrinsic factors such as site exposure, soil type, soil texture and moisture content.

(b) External factors which are essentially the weather elements.

The external factors plus the intrinsic properties of location, exposure and soil reflectivity determine the amount of heating at the soil surface. The other intrinsic factors, like soil moisture content, determine how deeply and quickly the surface heating penetrates. Soil types vary greatly over the country and on occasion even within the same district. Stations only a few miles apart and having essentially equal air temperatures may have significantly different earth temperatures. Earth temperatures depend more on sunshine and rainfall than on air temperatures. In a forest, earth temperatures are nearly always lower than in adjacent open sites. This is why thinning is usually effective in raising both soil and earth temperatures in a forest, more so when the soil is dry than when it is wet. Earth temperatures also decrease with elevation. Among the many factors playing a part are

(a) the decrease in solar radiation due to increased cloudiness

(b) the change in the soil type which is usually towards more peat

(c) the increase in rainfall and in wind.

Compared with adjacent lowland, a mountain site has less heat reaching and penetrating the surface and its ability to conduct heat downwards is less. R.W. Gloyne [ref. (2)] has produced an estimate of 5.5°C for the rate of the annual average decrease in earth temperature per 1000 metres. While this is a very rough estimate it is the best figure available for the lapse rate of earth temperature. For each station its latitude, longitude and height above sea level are given together with a brief description of the soil type as determined by the Soils Division of An Foras Taluntais. When estimating earth temperatures for an area the nearest available station with similar topography and soil should be used.

Change of Site.

There was a change of site at Shannon Airport in June 1969 from a poorly drained gley soil of clay loam to a free-draining sandy soil. The method of determining the effect of such changes is by reference to a nearby site which has not been subjected to any disturbance. It is found that the difference in earth temperatures between nearby stations is almost constant; so by examining the difference in each month, before and after the site change, the effect of the new site can be estimated. A

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reliable value of this difference is obtained only from a period in which the temperatures undergo a reasonable range of variation, both above and below the mean value. For earth temperatures this period is 13 years or more. The period since 1969 is only about half this. A further difficulty is that the nearest stations are Mallow and Birr. These two factors render uncertain the efficacy of the corrections; hence it was decided to publish two tables for Shannon Airport. The first ignores the effect of the change of site. The second attempts to correct the months which the tests indicate are affected by the change. Since, in the latter table, the 1956-'69 values are calculated from readings at another station no annual or extreme values are included.

Variation of Temperature with Depth.

Conduction is the main mode of heat transfer in the ground. In the top layers of soil other processes of heat transfer are important; these include movement of water, evaporation and the condensation and diffusion of water vapour. At 30, 60 and 120 cm. levels the classical theory of heat conduction might be expected to apply.

This presumes that at any point the rate of temperature change with time depends on

(1) the difference in temperature between it and neighbouring points

(2) the thermal diffusivity of the soil (K) which is a measure of the ease with which the soil changes temperature.

Assuming that the soil temperature varies only with depth (z) and that the diffusivity (K) is constant the conduction process is expressed mathematically by the Fourier equation $\frac{\partial T}{\partial t} = K\frac{\partial^2 T}{\partial z^2}$ where T is the temperature and t represents the time. For a simplified treatment of the Fourier equation see Appendix (B).

We may picture surface oscillations, such as the diurnal or annual variation of temperature, as producing a corresponding temperature fluctuation in the soil. The temperature wave is delayed as it penetrates into the ground and its amplitude decreases. The amount of delay and damping is determined by the diffusivity K. In units of cm^2 per sec, K varies from 0.02 for concrete to 0.002 for dry, sandy, soil. For a given soil K is dependent on moisture content since water is a much better conductor of heat than any other soil constituent. For wet sand K is about 0.007. Wet clay has a high diffusivity which may exceed 0.01 but very dry clay has K values as low as 0.002. The assumption of constant diffusivity is not very realistic and the results obtained from solving the Fourier equation with a constant K value are subject to this limitation, among others. Considerable insight into

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the process of heat transfer can, nonetheless, be gained from the simplified theory. An average value of K= 0.008 cm^2 per sec is used in the calculations which follow.

Result (2) obtained in Appendix (B) may be put in the following form:

$$\log_{10}\frac{R_o}{R_z} = (0.00262)\frac{z}{\sqrt{K}}$$

If K = 0.008 cm^2 per sec., $\log_{10}\frac{R_o}{R_z} = (0.029)z$

where R_o = daily temperature range (^oC) at the surface

R_z = daily temperature range (^oC) at depth z(cm)

Result (3) becomes $t_z - t_o = \frac{z(82 \cdot 9)}{\sqrt{K}}$ secs, where t_o = time of occurence of a temperature extreme at the surface, t_z = time of arrival of that temperature extreme at level z(cm).

If K = 0.008 cm^2 per sec. the time lag between the surface and level z, $t_z - t_o = (0.258)z$ hours.

The conduction theory predicts that (with K = 0.008) the daily temperature wave will be halved in amplitude for each 10 cm. increase in depth and that the maxima (and minima) will be delayed by 2½ hours. At 30 cm. the delay would be about 7½ hours. A 0900 GMT reading corresponds to a 0130 GMT surface value and is something in the nature of a minimum temperature. The 30 cm. daily range is one eighth of the daily range at the surface. A rough estimate of the latter range is 7^{o}C and hence the daily range at 30 cm. is about 1^{o}C. At 60 cm. the daily range is about one sixtieth of the surface value and at 120 cm. the daily range is quite negligible.

The annual temperature wave is reduced more slowly than the daily wave and penetrates $\sqrt{365}$ or 19 times as far before being reduced a like amount. It can still be detected in practice down to 1000 cm. The time lag of the annual wave is 19 times that of the daily wave and amounts to 5 hours per cm.or 6 days per ft.

In practice it is found that the time lag of the maximum daily temperature is predicted tolerably well but this is often not the case with the minimum.

Depth of Frost Penetration.

Soil water freezes just below 0^{o}C in clean sandy soils, in the range -2^{o}C to -4^{o}C in mineral soils and about -5^{o}C in clay soils [ref. (3)]. A duration factor must also be taken into account. Air temperatures just below 0^{o}C for a long period have the same effect as air temperatures well below 0^{o}C for a short spell. There is a "zero curtain effect" in the freezing process. As soon as any soil water in the top layer freezes there is a release of latent heat. The temperature in the partly frozen layer rises towards 0^{o}C and tends to remain steady until all the available water in the layer has frozen. The greater the soil water content the slower is frost penetration and the longer the period of the zero curtain. In light porous soils frost penetrates more deeply than in heavy soils. Similarly,

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once ice has formed in a layer, the temperature of that layer cannot rise above 0°C until all the ice has melted. During a cold spell the temperature in the ground can hover close to 0°C for a considerable time. In 1963, between Jan 24th and Feb 11th the 30 cm. earth temperature at Kilkenny ranged from +0.1°C to +0.3°C, in a sandy loam soil. No instance of a 30 cm. earth temperature below 0°C has been recorded at our synoptic stations. However, the effect of grass cover is to raise the temperature in winter and to lower it in summer compared with bare soil. Depth of frost penetration is greater in sandy than in loam or clay soils and is deeper in compacted soils than in loose or vegetation covered soils [ref.(3)].

Extreme Seasons 1956-'75.

In 1959 and 1975 the summers were very warm and dry. Mild winters occurred in 1956-'57 and 1970-'75. The most notable extreme was the very severe winter of 1962-'63. On Feb 4th 1963, Valentia Observatory recorded 1.4°C at 30cm., its lowest 30 cm. value since the 1.4°C of Jan 19th 1940. At Birr the value of 0.3°C read on Jan 26th 1963 compares with 0.5°C recorded on Jan 22nd 1940 but there was a change of site in the interim.

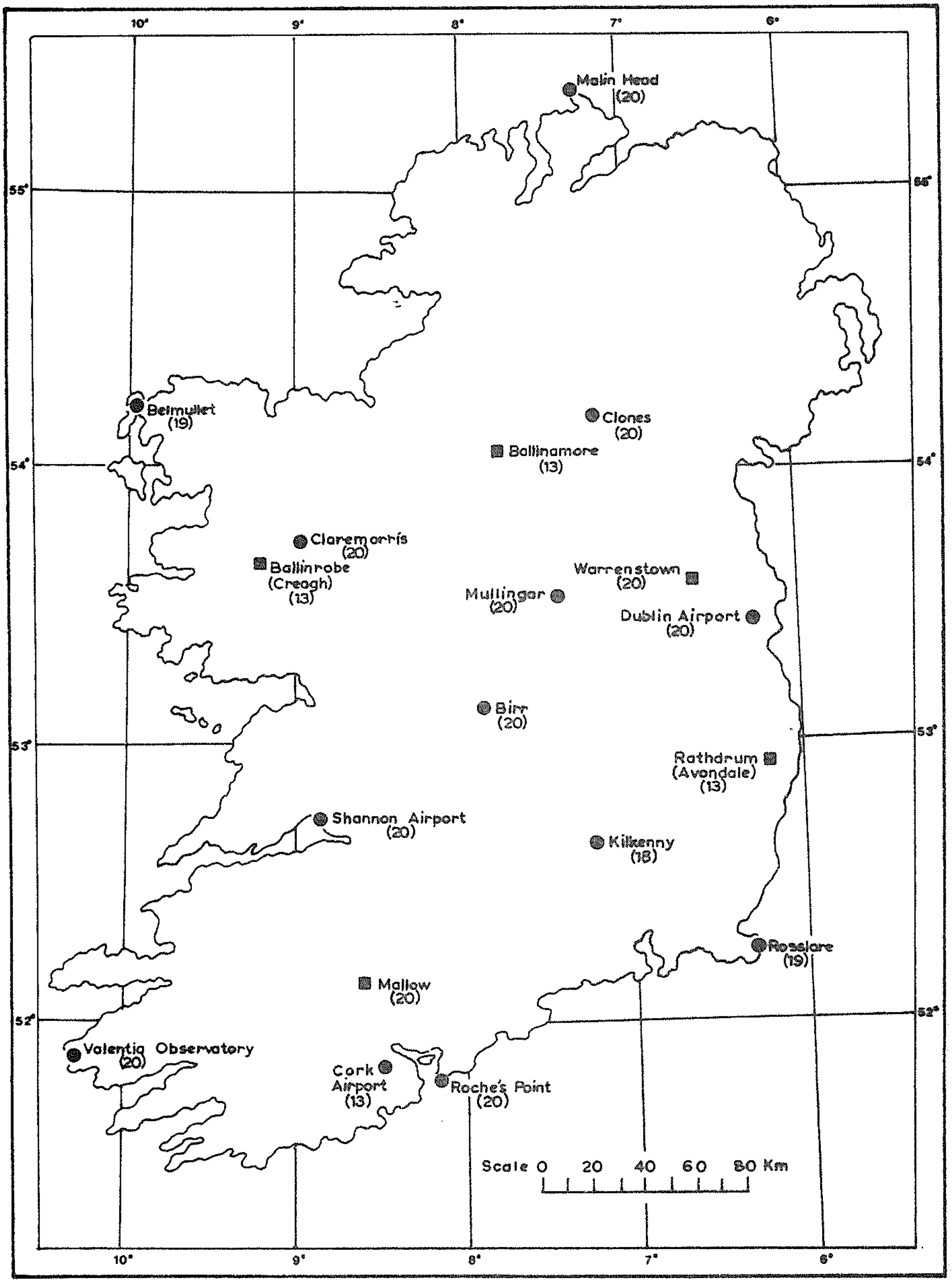
Distribution of the Earth Temperatures about the Mean Values.

Mean monthly temperature distributions are often of normal form. Among other properties this implies that nineteen out of twenty values should lie within two standard deviations above or below the mean value. In Appendix(C) the results of the test of normality are discussed. The fit of a normal curve to the data varies from good to poor. However, the rule that only 5% of values are more than two standard deviations from the mean held reasonably well when the 1956-'75 means and standard deviations were used to predict the 30 cm. temperature range for earlier periods. This suggests that using the 1956-'75 statistics to make assertions about future ranges of the 30 cm. temperatures should give fairly good results. At the 120 cm. level, the 1956-'75 statistics gave poor estimates of the temperature range for earlier periods and cannot be used to predict future values with any confidence (see Appendix C).

Comparison of the 1956-'75 Earth Temperature Means with those of the period 1931-'55 at Valentia Observatory

Depth	Period	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
30cm.	1956-'75	6.7	6.6	8.0	9.9	12.5	15.1	16.2	16.1	14.7	12.2	9.3	7.8
30cm.	1931-'55	6.5	6.4	7.7	10.0	12.8	15.3	16.6	16.7	14.9	12.2	9.1	7.4
120cm.	1956-'75	9.0	8.5	8.6	9.6	11.1	12.9	14.1	14.7	14.4	13.3	11.7	10.2
120cm.	1931-'55	8.3	7.9	8.2	9.7	11.4	13.3	14.7	15.4	14.9	13.3	11.2	9.5

The months November to February were colder in the period 1931-'55, while the period May to September was warmer. The differences are more pronounced at 120cm. For December, the 1931-'50 mean at 120cm. was 9.2°C and there has been a tendency for warmer Decembers since 1950.



EARTH TEMPERATURE STATIONS

● Synoptic station with earth thermometers at 30, 60 and 120 cm.

■ Climatological station with earth thermometers at 30 and 120 cm.

( ) Years of continuous record in the period 1956 - 1975

Belmullet, Co. Mayo.

$54^{\circ}14'N$ $10^{\circ}00'W$ Height: 9m.

Period of Record: 1957-1975.

Soil Type: Black humose loamy sand.

30 cm

Month	Average 1957-75	Standard Deviation from Average	Extreme monthly mean values 1957-75	
			Maximum	Minimum
Jan.	5.9	1.03	7.0	2.9
Feb.	5.9	1.01	7.1	3.0
Mar.	7.0	.85	8.8	5.8
Apr.	9.2	.76	10.5	7.3
May	11.8	.61	12.8	10.6
June	14.6	.75	16.2	13.2
July	15.6	.49	16.6	14.6
Aug.	15.6	.60	16.8	14.6
Sept.	14.2	.72	15.6	13.1
Oct.	11.9	.82	13.2	10.0
Nov.	8.8	.75	10.1	7.5
Dec.	7.2	.75	8.9	5.8
Year	10.7	.43	11.5	9.6

60 cm

Month	Average 1957-75	Standard Deviation from Average	Extreme monthly mean values 1957-75	
			Maximum	Minimum
Jan.	6.8	.77	7.6	4.5
Feb.	6.5	.85	7.5	3.9
Mar.	7.3	.72	8.9	6.3
Apr.	9.1	.64	10.3	8.1
May	11.4	.57	12.4	10.3
June	13.9	.58	15.2	12.8
July	15.1	.46	15.9	14.4
Aug.	15.4	.50	16.3	14.5
Sept.	14.4	.62	15.6	13.4
Oct.	12.5	.75	13.6	10.5
Nov.	9.9	.67	11.0	8.3
Dec.	8.1	.57	9.5	7.1
Year	10.9	.37	11.6	9.9

120 cm

Month	Average 1957-75	Standard Deviation from Average	Extreme monthly mean values 1957-75	
			Maximum	Minimum
Jan.	7.8	.57	8.5	6.4
Feb.	7.3	.65	8.1	5.1
Mar.	7.5	.57	8.7	6.3
Apr.	8.8	.55	9.8	7.7
May	10.6	.49	11.6	9.5
June	12.7	.43	13.6	12.0
July	14.0	.40	14.8	13.4
Aug.	14.6	.42	15.2	13.9
Sept.	14.2	.50	15.1	13.2
Oct.	12.9	.55	13.9	11.6
Nov.	10.9	.53	11.9	9.8
Dec.	9.1	.49	10.3	8.2
Year	10.9	.34	11.5	10.0

Birr, Co. Offaly

53^{o} 05'N 7^{o}53'W - Height 70m.

Period of Record: 1956-1975

Soil Type: Sandy clay loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	4.8	1.25	6.7	1.1
Feb.	4.9	1.36	6.9	1.7
Mar.	6.5	1.02	8.9	4.9
Apr.	9.0	.69	10.4	7.9
May	12.1	.76	13.6	10.4
June	15.2	.92	16.7	13.4
July	16.4	.77	18.4	15.2
Aug.	16.1	.75	18.0	14.7
Sept.	14.3	.74	15.8	13.3
Oct.	11.5	.87	13.1	9.7
Nov.	7.8	.82	9.2	6.5
Dec.	5.9	.84	7.6	4.4
Year	10.4	.47	11.3	9.2

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.6	1.04	7.3	2.7
Feb.	5.6	1.11	7.0	2.6
Mar.	6.8	.88	8.6	5.5
Apr.	8.9	.65	10.3	7.8
May	11.7	.62	13.0	10.3
June	14.5	.77	15.8	13.1
July	15.9	.70	17.8	14.8
Aug.	15.9	.66	17.6	14.8
Sept.	14.6	.69	15.9	13.6
Oct.	12.1	.71	13.6	10.6
Nov.	8.9	.74	10.2	7.7
Dec.	6.9	.66	8.0	5.6
Year	10.6	.42	11.5	9.6

120 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.0	.76	8.3	5.2
Feb.	6.6	.83	7.8	4.1
Mar.	7.1	.67	8.3	6.0
Apr.	8.5	.55	9.5	7.4
May	10.6	.43	11.4	9.5
June	12.9	.49	13.7	12.0
July	14.4	.57	15.9	13.4
Aug.	14.9	.51	16.2	14.2
Sept.	14.2	.58	15.4	13.2
Oct.	12.6	.55	13.9	11.6
Nov.	10.2	.56	11.2	9.3
Dec.	8.3	.47	9.2	7.5
Year	10.6	.39	11.4	9.7

Claremorris, Co. Mayo.

53°43'N 8°59'W Height 69m.

Period of Record: 1956-1975

Soil Type: Free-draining loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	4.9	1.11	6.5	1.6
Feb.	4.9	1.17	6.3	1.4
Mar.	6.2	.97	8.3	4.8
Apr.	8.4	.67	9.7	7.3
May	11.1	.59	12.2	9.9
June	13.8	.80	15.3	12.3
July	15.1	.63	16.4	14.1
Aug.	15.1	.80	16.9	13.9
Sept.	13.8	.70	14.7	12.5
Oct.	11.4	.84	13.0	9.5
Nov.	8.1	.81	9.5	6.5
Dec.	6.2	.69	7.7	5.2
Year	9.9	.43	10.7	8.9

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.7	.93	7.3	3.4
Feb.	5.5	.98	6.8	2.6
Mar.	6.5	.82	8.1	5.2
Apr.	8.2	.66	9.6	7.3
May	10.6	.46	11.3	9.5
June	13.1	.68	14.4	11.9
July	14.5	.60	15.7	13.4
Aug.	14.7	.72	16.4	13.7
Sept.	13.8	.68	14.9	12.6
Oct.	11.8	.65	13.0	10.4
Nov.	9.0	.76	10.2	7.4
Dec.	7.1	.61	8.2	5.8
Year	10.0	.42	10.9	9.1

120 cm

Month	Average 1956-75	Standard Deviation from average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.2	.67	8.3	5.9
Feb.	6.7	.72	7.7	4.4
Mar.	6.9	.62	8.0	5.7
Apr.	7.9	.53	9.1	7.0
May	9.6	.38	10.2	8.6
June	11.5	.45	12.3	10.8
July	13.0	.49	14.0	12.1
Aug.	13.7	.55	14.9	12.8
Sept.	13.4	.57	14.4	12.4
Oct.	12.2	.53	13.1	11.3
Nov.	10.3	.59	11.3	9.3
Dec.	8.5	.51	9.6	7.6
Year	10.1	.38	10.8	9.2

Clones, Co. Monaghan.

54°11'N 7°14'W Height 87m.

Period of Record: 1956-1975

Soil Type: Well-drained loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	4.5	1.24	6.6	1.0
Feb.	4.4	1.23	6.1	1.0
Mar.	5.8	1.08	7.9	4.0
Apr.	8.2	.81	9.7	6.8
May	11.4	.93	13.3	10.0
June	14.3	.97	16.0	11.8
July	15.4	.62	16.8	14.4
Aug.	15.3	.62	16.6	14.3
Sept.	13.8	.59	14.8	12.8
Oct.	11.2	.66	12.4	9.8
Nov.	7.7	.69	9.2	6.7
Dec.	5.7	.87	7.2	3.9
Year	9.8	.40	10.6	8.9

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.2	1.04	6.9	2.4
Feb.	5.0	1.04	6.3	1.8
Mar.	6.1	.92	7.9	4.6
Apr.	8.2	.78	9.7	7.0
May	11.0	.83	12.6	9.7
June	13.7	.87	15.4	11.7
July	14.9	.62	16.2	13.9
Aug.	15.1	.57	16.2	14.1
Sept.	14.0	.56	14.9	13.0
Oct.	11.7	.59	12.7	10.2
Nov.	8.6	.59	9.7	7.7
Dec.	6.5	.66	7.7	5.2
Year	10.0	.38	10.7	9.1

120 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	6.6	.80	7.9	4.8
Feb.	6.1	.85	7.3	3.6
Mar.	6.5	.71	7.6	5.0
Apr.	7.8	.59	8.9	6.9
May	9.8	.55	11.0	9.2
June	12.0	.59	13.2	10.8
July	13.4	.53	14.5	12.5
Aug.	14.0	.45	14.9	13.1
Sept.	13.6	.47	14.4	12.9
Oct.	12.2	.44	12.9	11.3
Nov.	10.0	.47	10.8	9.3
Dec.	8.0	.55	9.0	7.1
Year	10.0	.33	10.5	9.1

Dublin Airport, Co. Dublin.

53°26'N 6°14'W - Height 68m.

Period of Record: 1956-1975.

Soil Type: Moderately well-drained loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	4.7	1.12	6.5	1.8
Feb.	4.7	1.09	6.3	2.1
Mar.	6.1	1.14	8.3	4.2
Apr.	8.6	.72	10.0	7.2
May	11.8	.85	13.3	9.9
June	15.3	.97	16.9	12.9
July	16.4	.85	18.1	15.1
Aug.	16.0	.88	18.0	14.3
Sept.	14.1	.84	15.8	12.9
Oct.	11.2	.99	13.2	9.3
Nov.	7.6	.79	9.0	6.2
Dec.	5.7	.79	7.4	4.6
Year	10.2	.46	11.1	9.3

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.6	.92	7.2	3.4
Feb.	5.5	.88	6.6	3.0
Mar.	6.5	.88	8.3	5.1
Apr.	8.7	.72	9.9	7.4
May	11.5	.69	12.7	10.1
June	14.6	.83	16.0	12.8
July	15.9	.81	17.7	14.4
Aug.	15.9	.76	17.9	14.8
Sept.	14.6	.72	15.8	13.6
Oct.	12.1	.81	13.9	10.5
Nov.	8.9	.69	10.1	7.8
Dec.	6.8	.58	8.1	5.7
Year	10.6	.45	11.5	9.6

120 cm

Month	Average 1956-75	Standard Deviation from average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.0	.69	8.3	5.5
Feb.	6.5	.67	7.5	4.4
Mar.	6.9	.69	8.1	5.6
Apr.	8.3	.61	9.4	7.3
May	10.4	.51	11.4	9.6
June	12.9	.62	13.8	11.6
July	14.5	.69	16.3	13.3
Aug.	15.0	.69	16.9	13.9
Sept.	14.4	.62	15.6	13.4
Oct.	12.7	.58	14.1	11.8
Nov.	10.3	.57	11.4	9.4
Dec.	8.3	.50	9.2	7.3
Year	10.6	.42	11.6	9.7

Kilkenny, Co. Kilkenny.

52°40'N 7°16'W Height: 63m.

Period of Record: 1958-1975.

Soil Type: Well-drained gravelly sandy loam.

30 cm

Month	Average 1958-75	Standard Deviation from Average	Extreme monthly mean values 1958-75	
			Maximum	Minimum
Jan.	4.5	1.27	6.3	0.9
Feb.	4.7	1.37	6.5	1.3
Mar.	6.0	.98	8.0	4.1
Apr.	8.6	.79	10.4	7.5
May	11.8	1.04	13.9	10.3
June	15.2	1.17	17.1	12.7
July	16.5	.82	18.0	15.1
Aug.	16.1	.83	18.2	14.7
Sept.	14.1	.94	15.8	12.2
Oct.	11.2	1.05	12.9	8.7
Nov.	7.4	.95	9.3	6.0
Dec.	5.5	.83	7.4	4.1
Year	10.1	.50	11.2	9.1

60 cm

Month	Average 1958-75	Standard Deviation from Average	Extreme monthly mean values 1958-75	
			Maximum	Minimum
Jan.	5.2	1.09	7.1	2.4
Feb.	5.4	1.17	6.9	2.2
Mar.	6.4	.88	8.1	4.8
Apr.	8.6	.77	10.2	7.6
May	11.5	.92	13.3	10.2
June	14.5	.98	16.4	12.6
July	15.9	.74	17.3	14.7
Aug.	15.9	.75	17.8	14.7
Sept.	14.5	.82	16.3	13.0
Oct.	11.9	.88	13.5	9.9
Nov.	8.6	.86	10.1	7.2
Dec.	6.4	.65	7.8	5.3
Year	10.4	.48	11.4	9.4

120 cm

Month	Average 1958-75	Standard Deviation from Average	Extreme monthly mean values 1958-75	
			Maximum	Minimum
Jan.	6.4	1.17	8.1	2.6
Feb.	6.2	.88	7.5	3.5
Mar.	6.7	.72	7.9	5.5
Apr.	8.1	.65	9.4	7.1
May	10.3	.69	11.7	9.2
June	12.7	.78	14.6	11.4
July	14.3	.70	15.8	13.2
Aug.	14.8	.60	16.3	13.8
Sept.	14.3	.69	15.9	13.2
Oct.	12.5	.70	13.8	11.0
Nov.	10.0	.67	11.1	9.1
Dec.	7.9	.51	8.8	7.0
Year	10.3	.48	11.2	9.2

Malin Head, Co. Donegal.

55° 22'N 07° 20'W Height 20m.

Period of Record: 1956-1975

Soil Type: Black humose friable loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.6	.82	6.8	3.3
Feb.	5.3	.83	6.3	3.1
Mar.	6.4	.86	8.1	4.8
Apr.	8.3	.68	9.4	6.8
May	11.0	.68	12.6	10.0
June	13.4	.64	14.7	11.8
July	14.3	.51	15.4	13.2
Aug.	14.4	.64	16.0	13.4
Sept.	13.3	.56	14.3	12.2
Oct.	11.1	.60	12.2	10.0
Nov.	8.3	.52	9.2	7.5
Dec.	6.6	.68	8.1	5.3
Year	9.8	.31	10.5	9.3

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	6.4	.64	7.5	4.7
Feb.	6.1	.63	6.9	4.2
Mar.	6.7	.71	8.2	5.4
Apr.	8.1	.63	9.2	7.0
May	10.3	.63	11.7	9.5
June	12.4	.48	13.7	11.4
July	13.5	.44	14.2	12.7
Aug.	13.9	.50	15.1	13.2
Sept.	13.2	.49	14.1	12.4
Oct.	11.5	.48	12.5	10.6
Nov.	9.2	.43	10.0	8.7
Dec.	7.5	.51	8.7	6.6
Year	9.9	.30	10.4	9.4

120 cm

Month	Average 1956-75	Standard Deviation from average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.4	.40	8.0	6.5
Feb.	6.9	.42	7.4	5.6
Mar.	7.1	.54	8.3	6.0
Apr.	7.9	.58	8.9	7.0
May	9.5	.51	10.4	8.7
June	11.1	.37	12.2	10.6
July	12.4	.37	13.1	11.8
Aug.	13.0	.40	13.9	12.3
Sept.	12.8	.41	13.5	12.2
Oct.	11.7	.36	12.5	11.0
Nov.	10.0	.34	10.5	9.4
Dec.	8.4	.37	9.1	7.6
Year	9.8	.26	10.3	9.5

Mullingar, Co. Westmeath.

53° 31'N 7° 21'W Height 108m.

Period of Record: 1956-1975.

Soil Type: Well-drained sandy clay loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	4.4	1.14	6.2	1.4
Feb.	4.4	1.19	6.0	1.0
Mar.	5.9	1.06	8.1	3.9
Apr.	8.4	.68	9.7	7.0
May	11.6	.80	13.1	10.2
June	14.9	.91	16.6	13.5
July	16.1	.80	17.6	14.8
Aug.	16.0	.72	17.1	14.8
Sept.	14.3	.83	15.7	12.6
Oct.	11.4	.90	13.1	9.3
Nov.	7.7	.70	8.8	6.5
Dec.	5.6	.81	7.1	4.2
Year	10.1	.45	10.8	9.0

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.2	.97	6.8	2.8
Feb.	4.9	.98	6.2	1.9
Mar.	5.9	.93	7.7	4.3
Apr.	8.1	.71	9.4	7.0
May	10.9	.69	12.2	9.8
June	13.8	.87	15.6	12.3
July	15.4	.74	16.8	14.0
Aug.	15.6	.70	16.7	14.5
Sept.	14.4	.76	15.7	13.1
Oct.	12.0	.76	13.5	10.1
Nov.	8.7	.72	10.1	7.4
Dec.	6.5	.68	7.7	5.4
Year	10.1	.44	10.8	9.1

120 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	6.4	.77	7.7	4.9
Feb.	5.9	.78	7.0	3.4
Mar.	6.2	.73	7.4	4.7
Apr.	7.6	.63	8.7	6.6
May	9.8	.51	10.8	8.8
June	12.2	.60	13.4	11.2
July	13.9	.60	15.0	12.7
Aug.	14.5	.72	15.6	12.8
Sept.	14.1	.66	15.3	13.1
Oct.	12.5	.66	13.9	11.0
Nov.	10.1	.60	11.2	8.9
Dec.	7.9	.56	8.9	7.0
Year	10.1	.42	10.7	9.1

Roche's Point, Co. Cork.

51° 48'N 8°15'W Height 40m.

Record of Period: 1956-1975.

Soil Type: Well-drained gravelly loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	6.5	1.08	8.1	3.1
Feb.	6.4	1.28	8.1	3.9
Mar.	7.3	.94	9.4	5.6
Apr.	9.0	.68	10.5	7.9
May	11.5	.83	13.8	10.4
June	14.1	.93	16.2	11.8
July	15.4	.49	16.4	14.4
Aug.	15.4	.53	16.3	14.4
Sept.	14.3	.70	15.5	13.2
Oct.	12.2	.86	13.8	10.3
Nov.	9.3	.95	10.8	7.7
Dec.	7.7	.64	8.9	6.2
Year	10.8	.38	11.3	9.9

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.2	.93	8.6	4.3
Feb.	6.9	1.07	8.3	4.4
Mar.	7.6	.85	9.3	6.1
Apr.	9.1	.66	10.5	8.2
May	11.3	.82	13.7	10.4
June	13.6	.88	15.9	11.6
July	15.1	.53	15.9	13.9
Aug.	15.3	.44	16.1	14.6
Sept.	14.5	.61	15.5	13.5
Oct.	12.7	.72	14.1	11.0
Nov.	10.1	.84	11.4	8.7
Dec.	8.4	.58	9.6	7.2
Year	11.0	.36	11.5	10.1

120 cm

Month	Average 1956-75	Standard Deviation from average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	8.2	.72	9.3	6.2
Feb.	7.7	.73	8.7	5.6
Mar.	7.9	.67	8.9	6.9
Apr.	8.8	.54	9.9	8.0
May	10.5	.58	12.2	9.7
June	12.4	.65	14.2	11.0
July	13.8	.58	14.9	12.6
Aug.	14.4	.39	15.1	13.7
Sept.	14.2	.51	14.9	13.2
Oct.	13.1	.80	15.6	11.7
Nov.	11.1	.65	12.2	10.0
Dec.	9.4	.48	10.4	8.7
Year	10.9	.32	11.3	10.1

Rosslare, Co. Wexford.

$52^{o}15'N$ $6^{o}20'W$. Height 23m.

Period of Record: 1957-1975.

Soil Type: Poorly-drained loam to clay loam.

30 cm

Month	Average 1957-75	Standard Deviation from Average	Extreme monthly mean values 1957-75	
			Maximum	Minimum
Jan.	6.3	1.08	7.7	2.8
Feb.	6.2	1.08	7.6	3.5
Mar.	7.3	1.00	9.3	5.8
Apr.	9.6	.77	11.1	8.3
May	12.4	.89	14.3	11.1
June	15.4	.92	17.2	13.4
July	16.9	.74	18.7	15.7
Aug.	16.8	.63	18.7	16.1
Sept.	15.3	.89	17.4	13.6
Oct.	12.6	.88	14.2	10.3
Nov.	9.2	.77	10.3	7.8
Dec.	7.3	.54	8.3	6.5
Year	11.3	.47	12.4	10.4

60 cm

Month	Average 1957-75	Standard Deviation from Average	Extreme monthly mean values 1957-75	
			Maximum	Minimum
Jan.	6.9	.89	8.2	4.2
Feb.	6.8	.92	7.8	4.2
Mar.	7.5	.87	9.1	6.3
Apr.	9.3	.70	10.7	8.2
May	11.9	.82	13.8	10.9
June	14.7	.90	16.4	12.7
July	16.2	.75	18.1	15.0
Aug.	16.5	.60	18.3	15.6
Sept.	15.4	.81	17.6	14.0
Oct.	13.1	.79	14.8	11.0
Nov.	10.1	.69	11.0	8.8
Dec.	8.1	.45	8.9	7.3
Year	11.4	.45	12.5	10.6

120 cm

Month	Average 1957-75	Standard Deviation from Average	Extreme monthly mean values 1957-75	
			Maximum	Minimum
Jan.	7.9	.67	8.8	6.0
Feb.	7.5	.71	8.2	5.1
Mar.	7.7	.71	8.9	6.4
Apr.	8.9	.63	10.1	8.0
May	10.9	.63	12.4	10.2
June	13.2	.74	14.7	11.8
July	14.8	.70	16.4	13.7
Aug.	15.4	.57	17.1	14.6
Sept.	15.0	.68	17.0	14.0
Oct.	13.4	.67	15.3	11.8
Nov.	11.1	.58	12.0	10.0
Dec.	9.1	.42	9.9	8.4
Year	11.3	.41	12.3	10.5

Shannon Airport, Co. Clare.

$52^{o}41'$N $8^{o}55'$W Height: 3m.

Period of Record: 1956-1975.

Soil Type: Poorly drained gley soil to 1969; then rapid draining loamy sand.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.4	1.24	7.3	1.7
Feb.	5.5	1.41	7.3	1.8
Mar.	7.0	.99	9.2	5.5
Apr.	9.5	.73	10.9	8.4
May	12.6	.86	14.0	11.1
June	15.5	1.00	17.4	13.3
July	16.6	.64	18.2	15.6
Aug.	16.3	.72	17.9	15.3
Sept.	14.8	.76	16.4	13.3
Oct.	12.1	.86	13.7	10.0
Nov.	8.5	.89	10.1	6.8
Dec.	6.6	.80	8.2	5.0
Year	10.9	.48	11.8	9.7

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.8	1.41	7.9	2.1
Feb.	5.7	1.39	7.6	1.6
Mar.	6.9	1.00	8.8	5.0
Apr.	9.0	.87	10.6	7.2
May	11.7	.79	13.0	9.8
June	14.5	1.04	16.8	12.8
July	15.8	.86	17.8	14.2
Aug.	15.9	.92	17.7	14.3
Sept.	14.8	.94	16.3	13.1
Oct.	12.4	.93	14.0	10.9
Nov.	9.2	.98	10.9	7.7
Dec.	7.2	1.04	8.5	5.2
Year	10.7	.77	11.9	9.0

120 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.6	.68	8.6	5.9
Feb.	7.0	.85	8.0	4.2
Mar.	7.5	.69	8.7	6.1
Apr.	8.8	.60	9.8	7.6
May	10.7	.52	11.7	9.6
June	13.0	.64	14.6	12.1
July	14.5	.66	16.2	13.3
Aug.	15.1	.54	16.5	14.4
Sept.	14.7	.58	15.8	13.8
Oct.	13.2	.59	14.3	11.7
Nov.	11.0	.56	11.9	9.7
Dec.	9.0	.44	9.8	8.4
Year	11.0	.38	11.7	10.0

Shannon Airport, Co. Clare.

Period of Record: 1956-1975.

Values for 1956-'69 were adjusted to new soil type (see notes)

Asterisk denotes changed value.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.4	1.24		
Feb.	*5.6	*1.35		
Mar.	7.0	.99		
Apr.	9.5	.73		
May	12.6	.86		
June	15.5	1.00		
July	16.6	.64		
Aug.	16.3	.72		
Sept.	14.8	.76		
Oct.	12.1	.86		
Nov.	8.5	.89		
Dec.	*6.9	* .66		
Year				

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	*6.0	*1.07		
Feb.	*6.1	*1.12		
Mar.	*7.3	* .88		
Apr.	*9.3	* .64		
May	*12.0	* .66		
June	14.5	1.04		
July	15.8	.86		
Aug.	15.9	.92		
Sept.	14.8	.94		
Oct.	12.4	.93		
Nov.	*9.5	*.75		
Dec.	*7.5	*.67		
Year				

120 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	* 7.3	* .74		
Feb.	* 6.9	* .83		
Mar.	7.5	.69		
Apr.	8.8	.60		
May	10.7	.52		
June	*13.1	* .69		
July	*14.6	* .56		
Aug.	15.1	.54		
Sept.	14.7	.58		
Oct.	13.2	.59		
Nov.	11.0	.56		
Dec.	* 8.9	* .41		
Year				

Valentia Observatory, Co. Kerry.

$51^{o}56'N$ $10^{o}15'W$ Height:- 9m.

Period of Record: 1956-1975.

Soil Type: Well-drained gravelly clay loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	6.7	1.29	8.3	2.5
Feb.	6.6	1.35	8.4	3.4
Mar.	8.0	.86	9.9	5.9
Apr.	9.9	.56	11.0	8.7
May	12.5	.75	13.4	10.8
June	15.1	.86	16.7	13.5
July	16.2	.54	17.5	15.5
Aug.	16.1	.78	17.4	14.6
Sept.	14.7	.83	16.5	13.1
Oct.	12.2	1.07	14.2	10.6
Nov.	9.3	1.03	11.0	7.7
Dec.	7.8	.97	9.4	5.8
Year	11.3	.58	12.1	9.8

60 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.5	.98	8.7	4.3
Feb.	7.3	1.07	8.5	4.5
Mar.	8.2	.74	9.6	6.8
Apr.	9.9	.53	11.0	8.9
May	12.1	.61	13.2	10.8
June	14.5	.68	15.7	12.9
July	15.7	.44	16.7	15.0
Aug.	15.8	.57	16.9	14.8
Sept.	14.8	.64	16.1	13.7
Oct.	12.8	.84	14.4	11.0
Nov.	10.3	.80	11.6	9.0
Dec.	8.7	.64	10.0	7.4
Year	11.5	.42	12.1	10.4

120 cm

Month	Average 1956-75	Standard Deviation from average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	9.0	.62	9.8	7.4
Feb.	8.5	.70	9.2	6.2
Mar.	8.6	.57	9.4	7.5
Apr.	9.6	.46	10.5	8.6
May	11.1	.38	11.7	10.0
June	12.9	.68	14.8	11.8
July	14.1	.47	14.8	12.9
Aug.	14.7	.44	15.4	13.9
Sept.	14.4	.50	15.3	13.4
Oct.	13.3	.53	14.5	12.3
Nov.	11.7	.55	12.7	10.8
Dec.	10.2	.44	11.1	9.6
Year	11.5	.37	12.0	10.5

Ballinamore Ag. Inst., Co. Leitrim.

$54^{o}04'N$ $07^{o}47W$ Height:- 80m.

Period of Record; 1963-1975.

Soil Type: Poorly drained gley soil of clay loam texture.

30 cm

Month	Average 1963-75	Standard Deviation from Average	Extreme monthly mean values 1963-75	
			Maximum	Minimum
Jan.	4.8	1.23	6.2	1.5
Feb.	4.4	1.21	5.7	1.4
Mar.	5.5	.68	6.6	4.1
Apr.	7.7	.70	9.1	6.5
May	10.4	.66	11.6	9.2
June	13.6	.71	14.8	12.0
July	14.7	.56	16.0	13.9
Aug.	14.9	.65	16.4	13.9
Sept.	13.3	.69	14.2	12.0
Oct.	11.0	.92	12.4	9.0
Nov.	7.6	.80	8.9	6.3
Dec.	5.9	.79	7.2	4.6
Year	9.5	.47	10.4	8.6

120 cm

Month	Average 1963-75	Standard Deviation from Average	Extreme monthly mean values 1963-75	
			Maximum	Minimum
Jan.	6.7	.58	7.5	5.5
Feb.	6.1	.75	7.1	4.1
Mar.	6.1	.62	6.8	5.0
Apr.	7.1	.46	8.0	6.4
May	8.9	.43	9.7	8.0
June	11.0	.40	11.7	10.4
July	12.7	.72	14.5	11.8
Aug.	13.2	.45	14.3	12.5
Sept.	12.9	.52	13.7	11.9
Oct.	11.7	.55	12.5	10.5
Nov.	9.7	.57	10.5	8.6
Dec.	8.0	.50	8.8	6.9
Year	9.5	.36	10.2	8.8

Ballinrobe (Creagh), Co. Mayo.

53°38'N 09°16'W Height:- 28m.

Period of Record: 1963-1975.

Soil Type: Moderately well-drained sandy loam.

30 cm

Month	Average 1963-75	Standard Deviation from Average	Extreme monthly mean values 1963-75	
			Maximum	Minimum
Jan.	5.6	1.27	6.8	2.0
Feb.	5.3	1.25	6.5	1.8
Mar.	6.5	.67	7.9	5.2
Apr.	8.8	.46	9.8	8.0
May	11.4	.55	12.3	10.3
June	14.7	.76	15.8	13.0
July	15.9	.40	16.5	15.2
Aug.	15.9	.66	17.2	14.8
Sept.	14.4	.77	15.4	13.0
Oct.	12.1	.92	13.6	10.2
Nov.	8.8	.84	10.2	7.0
Dec.	6.9	.69	8.2	5.6
Year	10.5	.39	11.1	9.6

120 cm

Month	Average 1963-75	Standard Deviation from Average	Extreme monthly mean values 1963-75	
			Maximum	Minimum
Jan.	7.3	.70	8.2	5.4
Feb.	6.6	.90	7.7	4.0
Mar.	7.0	.54	7.8	6.0
Apr.	8.3	.43	9.4	7.7
May	10.3	.34	10.8	9.7
June	12.8	.44	13.5	11.8
July	14.3	.52	15.4	13.6
Aug.	14.7	.25	15.0	14.1
Sept.	14.2	.53	15.0	13.2
Oct.	12.8	.78	13.8	10.5
Nov.	10.6	.84	11.6	8.2
Dec.	8.7	.60	9.8	7.7
Year	10.6	.30	11.0	9.9

Mallow C.S.E.T., Co. Cork.

52°08'N 08°42'W Height:- 56m.

Period of Record: 1956-1975.

Soil Type: Loamy sand.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.7	1.08	7.3	2.6
Feb.	5.7	1.35	7.7	3.0
Mar.	7.2	.95	9.3	5.8
Apr.	9.4	.60	10.9	8.6
May	12.1	.58	12.9	11.3
June	14.6	.91	16.5	13.3
July	16.0	.64	17.4	15.1
Aug.	15.9	.82	17.5	14.4
Sept.	14.6	.66	15.9	13.6
Oct.	12.3	.82	14.0	10.6
Nov.	9.1	.93	10.3	7.1
Dec.	7.0	.65	8.2	5.6
Year	10.8	.39	11.6	10.1

120 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	7.3	.69	8.3	5.7
Feb.	6.9	.84	8.3	4.7
Mar.	7.5	.77	8.8	5.9
Apr.	8.8	.56	10.1	7.9
May	10.7	.37	11.6	10.2
June	12.7	.58	14.0	11.8
July	14.1	.43	15.0	13.0
Aug.	14.7	.49	15.6	13.8
Sept.	14.3	.57	15.3	13.3
Oct.	13.0	.54	14.0	12.0
Nov.	10.8	.58	11.8	9.8
Dec.	8.8	.49	9.7	7.9
Year	10.8	.33	11.5	10.2

Rathdrum (Avondale), Co. Wicklow.

52°55'N 06°13'W Height 129m.

Period of Record: 1963-1975.

Soil Type: Well-drained Brown Earth.

30 cm

Month	Average 1963-75	Standard Deviation from Average	Extreme monthly mean values 1963-75	
			Maximum	Minimum
Jan.	4.9	1.12	6.5	2.1
Feb.	4.6	1.21	6.1	1.9
Mar.	5.6	.69	7.2	4.3
Apr.	8.1	.47	9.1	7.1
May	11.1	.65	12.1	10.0
June	14.4	.76	15.3	12.9
July	15.8	.52	16.6	15.0
Aug.	15.8	.42	16.4	15.1
Sept.	14.1	.59	15.0	13.3
Oct.	11.5	.81	12.7	9.8
Nov.	8.1	.81	9.0	6.7
Dec.	5.9	.69	7.2	4.8
Year	10.0	.30	10.4	9.4

120 cm

Month	Average 1963-75	Standard Deviation from Average	Extreme monthly mean values 1963-75	
			Maximum	Minimum
Jan.	6.7	.85	8.4	5.3
Feb.	6.0	.74	6.8	4.0
Mar.	6.2	.54	7.1	5.3
Apr.	7.4	.28	7.8	6.8
May	9.5	.32	10.0	8.7
June	11.8	.42	12.4	11.1
July	13.5	.49	14.5	12.7
Aug.	14.2	.34	14.7	13.6
Sept.	13.7	.40	14.4	12.9
Oct.	12.2	.51	13.1	11.3
Nov.	10.0	.53	10.7	9.2
Dec.	7.9	.53	8.8	6.8
Year	9.9	.28	10.4	9.3

Warrenstown Ag. Coll., Co. Meath.

53°31'N 06°37'W Height 87m.

Period of Record: 1956-1975.

Soil Type: Moderately well drained sandy clay loam.

30 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	4.6	1.46	6.9	1.4
Feb.	4.6	1.41	6.5	0.9
Mar.	6.1	1.18	8.2	3.6
Apr.	8.5	.84	10.3	7.2
May	11.5	.68	12.9	10.0
June	14.6	.83	16.1	13.1
July	16.0	.76	17.9	15.1
Aug.	15.7	.68	17.5	14.7
Sept.	14.0	.70	15.2	13.0
Oct.	11.2	.77	12.7	9.3
Nov.	7.8	.92	9.5	6.4
Dec.	5.8	1.01	8.0	4.0
Year	10.0	.48	11.0	9.0

120 cm

Month	Average 1956-75	Standard Deviation from Average	Extreme monthly mean values 1956-75	
			Maximum	Minimum
Jan.	5.9	1.01	7.8	3.9
Feb.	5.7	1.13	7.7	2.7
Mar.	6.1	.89	7.5	4.5
Apr.	7.7	.89	9.4	5.9
May	10.1	.60	11.7	9.3
June	12.7	.53	13.9	11.7
July	14.6	.70	16.4	13.6
Aug.	15.0	.66	17.0	14.2
Sept.	14.2	.62	15.6	13.5
Oct.	12.2	.57	13.3	10.9
Nov.	9.5	.74	11.0	8.4
Dec.	7.4	.70	9.0	6.1
Year	10.1	.45	11.1	9.1

Appendix A.

Length of record needed to obtain a stable frequency distribution.

The 30cm. records at three longer-term stations, Mallow, Warrenstown and Cahirciveen were used.

The mean $\bar{T}$ of a sample of n is obtained from

$$\bar{T} = \frac{1}{n} \sum_{i=1}^{i=n} T_i$$

The 'unbiased' estimate of the standard deviation(s) was calculated from

$$(n-1)s^2 = \sum_{i=1}^{i=n} (T_i - \bar{T})^2$$

$$\text{or } (n-1)s^2 = \sum_{i=1}^{i=n} T_i^2 - \frac{\left(\sum_{i=1}^{i=n} T_i\right)^2}{n}$$

where s^2 = variance

The range was determined by inspection. Each of these parameters was calculated for 10, 13, 15 and 20-year periods and also for periods between 20 and 30 years. The 13-year period was considered because a number of climatological stations opened during 1962. If we assume that our samples are taken from a (roughly) normal population, the estimate of the population mean obtained from the sample should have a standard deviation (error) of order $\frac{1}{\sqrt{n}}$. Further, the standard deviation of the variance (s^2) is of order $\sqrt{\frac{2}{n}}$. A 20-year period can be regarded as determining the long-term (population) mean to within about 0.2°C. Consequently, differences of 0.2°C or less between means for different periods will be ignored. The effect of convection, which can cause the 30cm. reading to be about 0.5°C too high on a hot summer day, is neglected. In the same way the variance (s^2) was regarded as stable when differences were less than or equal to 0.3°C. The tables which follow show that periods of 13 years give statistics within the assumed error of the 20-year values in nearly all cases. In addition 13-year statistics are reasonably close to the statistics for periods between 20 and 30 years. Hence, means calculated for 13 (or more) years of record may be taken, without adjustment for the missing years, as 20-year means and in most cases give a reasonable estimate of 30-year means.

The 120cm. means at Mallow and Warrenstown, and the 60cm. means at Valentia Observatory were similarly tested. The conclusions were essentially the same as for the 30cm. level.

MALLOW: 30cm.

MONTH	PERIOD	NUMBER OF YEARS	MEAN	S.D. AND VARIANCE (s^2)	RANGE
JANUARY	1966-'75	10	6.2	0.72 (0.52)	2.0
	1963-'75	13	5.8	1.20 (1.45)	4.7
	1961-'75	15	5.7	1.16 (1.41)	4.7
	1956-'75	20	5.7	1.08 (1.16)	4.7
	1951-'75	25	5.7	1.00 (1.00)	4.7
APRIL	1966-'75	10	9.4	0.44 (0.19)	1.5
	1963-'75	13	9.3	0.43 (0.19)	1.5
	1961-'75	15	9.4	0.60 (0.36)	2.3
	1956-'75	20	9.4	0.60 (0.37)	2.3
	1951-'75	25	9.3	0.60 (0.36)	2.5
JULY	1966-'75	10	16.4	0.49 (0.24)	1.6
	1963-'75	13	16.2	0.58 (0.33)	2.1
	1961-'75	15	16.1	0.64 (0.41)	2.3
	1956-'75	20	16.0	0.64 (0.41)	2.3
	1951-'75	25	16.0	0.66 (0.43)	2.3
OCTOBER	1966-'75	10	12.5	1.10 (1.21)	3.4
	1963-'75	13	12.4	0.97 (0.94)	3.4
	1961-'75	15	12.4	0.93 (0.86)	3.4
	1956-'75	20	12.3	0.82 (0.67)	3.4
	1951-'75	25	12.3	0.82 (0.67)	3.4

The 10-year period gives an inadequate estimate of the 20 or 25-year means in January and July but the 13-year mean is adequate in all cases. In January the 13-year variance estimate is just about adequate for the 20-year period but is beyond the limit of error allowed for the 25-year period.

At 120cm. the 13-year period was adequate in all the months tested.

WARRENSTOWN: 30 cm.

MONTH	PERIOD	NUMBER OF YEARS	MEAN	S.D. AND VARIANCE (s^2)	RANGE
FEBRUARY	1966-'75	10	5.4	0.90 (0.81)	2.7
	1963-'75	13	4.8	1.53 (2.34)	5.6
	1961-'75	15	4.9	1.45 (2.09)	5.6
	1956-'75	20	4.6	1.41 (1.98)	5.6
	1952-'75	24	4.4	1.39 (1.93)	5.6
MAY	1966-'75	10	11.3	0.69 (0.48)	2.1
	1963-'75	13	11.3	0.60 (0.36)	2.1
	1961-'75	15	11.4	0.72 (0.51)	2.9
	1956-'75	20	11.5	0.68 (0.46)	2.9
	1952-'75	24	11.6	0.77 (0.60)	3.4
AUGUST	1966-'75	10	15.8	0.69 (0.47)	2.4
	1963-'75	13	15.7	0.67 (0.45)	2.6
	1961-'75	15	15.6	0.69 (0.47)	2.8
	1956-'75	20	15.7	0.68 (0.46)	2.8
	1952-'75	24	15.9	0.88 (0.77)	3.6
NOVEMBER	1966-'75	10	8.0	1.09 (1.19)	3.1
	1963-'75	13	7.9	0.97 (0.95)	3.1
	1961-'75	15	7.8	0.96 (0.92)	3.1
	1956-'75	20	7.8	0.92 (0.85)	3.1
	1952-'75	24	7.7	0.90 (0.81)	3.4

In February the 10-year statistics give a poor estimate of the 20 or 24-year values. The 13-year mean is just adequate as an estimator of the 20-year mean but is inadequate as an estimator for the 24-year period, in both February and May. In May the 10-year variance is closer to the 20 and 24-year estimates than is the 13-year value. In August the difference between the 20 and 24-year statistics is due to the very high 30 cm. temperature (18.3°C) in 1955. At 120cm., the 13-year mean was 0.3°C higher than 1956-'75 mean in January but was within the allowed difference in all other months. In November and December the 1963-'75 means were 0.3°C higher than the 1952-'75 values.

VALENTIA OBSERVATORY 30 cm.

MONTH	PERIOD	NUMBER OF YEARS	MEAN	S.D. AND VARIANCE (S^2)	RANGE
JANUARY	1966-'75	10	7.4	0.67 (0.45)	1.9
	1963-'75	13	6.8	1.56 (2.44)	5.8
	1961-'75	15	6.7	1.48 (2.18)	5.8
	1956-'75	20	6.7	1.29 (1.68)	5.8
	1951-'75	25	6.6	1.21 (1.48)	5.8
	1946-'75	30	6.6	1.17 (1.37)	5.8
APRIL	1966-'75	10	10.0	0.39 (0.15)	1.3
	1963-'75	13	9.9	0.52 (0.27)	2.3
	1961-'75	15	9.9	0.59 (0.35)	2.3
	1956-'75	20	9.9	0.56 (0.31)	2.3
	1951-'75	25	9.9	0.59 (0.35)	2.4
	1946-'75	30	9.9	0.60 (0.36)	2.4
JULY	1966-'75	10	16.5	0.54 (0.29)	1.6
	1963-'75	13	16.4	0.56 (0.31)	2.0
	1961-'75	15	16.3	0.57 (0.33)	2.0
	1956-'75	20	16.2	0.54 (0.30)	2.0
	1951-'75	25	16.4	0.77 (0.60)	3.7
	1946-'75	30	16.4	0.79 (0.62)	3.7
OCTOBER	1966-'75	10	12.7	1.26 (1.60)	3.6
	1963-'75	13	12.4	1.17 (1.36)	3.6
	1961-'75	15	12.3	1.15 (1.32)	3.6
	1956-'75	20	12.2	1.07 (1.14)	3.6
	1951-'75	25	12.2	0.98 (0.97)	3.6
	1946-'75	30	12.3	0.95 (0.90)	3.6

In January, April and October we have the usual trend with the mean becoming more or less constant as the period of record increases. The 13-year statistics are good estimates of even the 30-year statistics except for the October variance. In July the 10 and 13-year means are closer to the 30-year mean than the 20-year value; but 1955 had the warmest July at 30 cm. of the whole 1946-'75 period, while 1949 had the second warmest. Furthermore, in July 1954 the temperature recorded at 30 cm. was 0.7°C lower than in any July of the 1956-'75 period. At 60cm. the 13-year means and variances differed from the 20-year values by less than the error allowed.

Appendix (B)

Simplified Solution of the Heat Conduction Equation.

We neglect any horizontal variations in temperature T and consider T as a function of depth (z) and time (t)

The Fourier equation is

$$\frac{\partial T}{\partial t} = K\frac{\partial^2 T}{\partial z^2}$$

By inspection a solution is $T(z,t) = f_1(t - \frac{z}{\sqrt{K}}) + f_2(t + \frac{z}{\sqrt{K}})$ where f_1 and f_2 are arbitrary functions which may be interpreted as waves travelling down and up the z - axis. We are interested only in downward-travelling waves and so consider solutions of form $T = f_1(t - \frac{z}{\sqrt{K}})$ In order to specify the form of f_1 we must presume a functional form for the temperature at a boundary. A first approximation to the surface temperature variation is $T(0,t) = T_0 + A_0 \cos wt$ i.e. the surface temperature has a mean value T_0, a maximum $T_0 + A_0$ and a minimum $T_0 - A_0$ as wt varies from 0 to 2π during the cycle (daily or annual). For convenience use $T(0,t) = T_0 + A_0 e^{iwt}$ where $i = \sqrt{-1}$ and $e^{i\theta} = \cos\theta + i\sin\theta$ By analogy with the procedure in the case of ordinary differential equations consider a solution $T(z,t) = \bar{T} + A(e^{at + bz})$ where $\bar{T}$, A, a and b are constant.

Setting $z = 0$ $T(0,t) = \bar{T} + Ae^{at}$

We get

$$A = A_0$$
$$\bar{T} = T_0$$
$$a = iw$$

Substituting for $T(z,t)$ in the heat conduction equation we get

$$a = iw = Kb^2$$
$$b = \pm\sqrt{\frac{w}{K}} \cdot \sqrt{i} = \pm\sqrt{\frac{w}{K}} \cdot \frac{(1+i)}{\sqrt{2}}$$

Since $T(z,t)$ must be finite as z approaches infinity the negative sign must be taken

Then

$$T(z,t) = T_0 + A_0 e^{iwt - \sqrt{\frac{w}{2K}} \cdot (1+i)z}$$
$$= T_0 + A_0 e^{-z\sqrt{\frac{w}{2K}}} \; e^{i(wt - z\sqrt{\frac{w}{2K}})}$$

Taking the real part

$$T(z,t) = T_0 + A_0 e^{-z\sqrt{\frac{w}{2K}}} \cos(wt - z\sqrt{\frac{w}{2K}})$$

The solution represents a wave undergoing an exponential decay in amplitude and a change of phase as it travels downwards into the soil.

Decay in Amplitude.

Let P = period of the oscillation (daily or annual)

Angular Frequency $w = \frac{2\pi}{P}$ (P = 86,400 secs for the daily vibration)

Ratio of the amplitudes of the temperature wave at depths Z_2 and Z_1

$$= \frac{e^{-z_2\sqrt{\frac{\pi}{PK}}}}{e^{-z_1\sqrt{\frac{\pi}{PK}}}}$$

Ranges of temperature at z_2 and z_1 are related by

$$\frac{Rz_2}{Rz_1} = e^{(z_1 - z_2)\sqrt{\frac{\pi}{PK}}} \quad \text{........1}$$

$$\text{if} \quad z_1 = 0 \qquad \frac{Rz_2}{Rz_1} = e^{-z_2\sqrt{\frac{\pi}{PK}}} \quad \text{........2}$$

Time Lag

Suppose a temperature maximum occurs at the surface at time $t = t_0$

Then $wt = 0$ (or 2π)

This temperature maximum is propagated downwards and it reaches the depth z_1 at a time t_1 given by $\frac{2\pi}{P} t_1 - z_1\sqrt{\frac{\pi}{PK}} = 0$

It reaches the depth z_2 at a time t_2 given by $\frac{2\pi}{P} t_2 - z_2\sqrt{\frac{\pi}{PK}} = 0$

Time lag between the surface maximum and the maximum at z_1

$$= t_1 - t_0 = \frac{z_1}{2}\sqrt{\frac{P}{\pi K}} \quad \text{...........3}$$

Time lag between depth z_1 and z_2

$$= t_2 - t_1 = \frac{(z_2 - z_1)}{2}\sqrt{\frac{P}{\pi K}} \quad \text{......4}$$

A similar argument produces the same formulae for the time lag of minima.

Applicability of the Formulae.

The assumption $T(0,t) = T_0 + A_0 \cos wt$ fits best on fine days in summer and does not represent the nocturnal temperature wave well. This is because the period between minimum and maximum is shorter than (not equal to) the period between maximum and minimum. Since the heat conduction equation is linear, the sum of any number of solutions is also a solution. If the daily temperature wave is represented at the surface by the series $T(0,t) = T_0 + \sum_{n=1}^{n=k} A_n \cos nwt$ the solution is

$$T(z,t) = T_0 + \sum_{n=1}^{n=k} A_n e^{-z\sqrt{\frac{nw}{2K}}} \cos\left(nwt - z\sqrt{\frac{nw}{2K}}\right)$$

For a daily temperature wave to be well represented we usually need to take k=2 or 3 [ref. (4)] and formulae (1) to (4) apply only moderately well. However, the annual temperature wave is well represented by a single harmonic ($n = 1$) and formulae (1) to (4) apply quite well.
For a more detailed treatment of the heat conduction equation see ref (5).

Appendix C.

Tests of Normality.

The tests used were those in Pearson and Hartley's Biometrica Tables (1956) pages 61 to 63 and consisted of a test of skewness and Geary's test of kurtosis.

Results were: (1) Marked skewness in some months particularly in January and February. The extreme values in 1963 caused the negative skewness in these months.

(ii) Geary's test of kurtosis gave results ranging from poor to good. The failure to fulfil this necessary condition in a sufficient number of cases means that a general assumption of normality cannot be made.

Making the narrower assumption that 19 out of 20 values fall within two standard deviations of the mean it is found that the 1956-'75 data obeys the rule well at all three levels. To test whether this rule can be used to forecast, the 1931-'55 data at 30cm. and 120cm. for Valentia were examined. The 1956-'75 means and standard deviations were used to set the limits. The expected score is 23 or 24. The following were the results:-

Valentia Observatory

Depth Period

120cm. 1931-'55

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Score	19	23	20	23	19	24	20	17	22	24	20	11

Depth Period

30cm. 1931-'55

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Score	25	24	22	20	25	24	19	23	25	25	24	22

Depth Period

30cm. 1946-'55

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Score	10	9	8	9	10	10	6	8	10	10	10	9

At 120cm. the rule was a total failure in Jan, March, May, July, Aug, Nov and Dec for the period 1931-'55.

At 30cm. the results were better. The rule failed badly in April and July. Results in March and Dec. were barely acceptable but for 8 months the results were good. By taking a shorter period (1946-'55) we find the rule failing badly in July. Results in March and August were hardly acceptable but for the other nine months, the rule was valid. The rule failed for April in 1931-'55 but gave good results for the 1946-'55 period.

The number of failures and the particular months in which the rule fails depends on the similarity of the period chosen to 1956-'75. Tentatively we may use 1956-'75 means and standard deviations to forecast ranges for the 30cm. temperatures. While the 1956-'75 statistics may adequately describe future values of the 120cm. temperatures the evidence indicates that this is unlikely. Using the 1946-'55 period the number of total failures reduces from 7 to 5 but this is still much too high.

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