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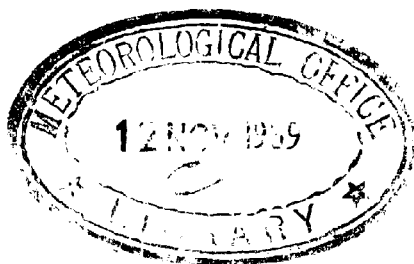
METEOROLOGICAL OFFICE

PROFESSIONAL NOTES NO. 125

(Fifth Number of Volume VIII)

AVERAGES OF ACCUMULATED TEMPERATURE
AND STANDARD DEVIATION OF MONTHLY MEAN
TEMPERATURE OVER BRITAIN, 1921-50

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LONDON
HER MAJESTY'S STATIONERY OFFICE
1959
TWO SHILLINGS NET

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MONTHLY AVERAGES OF ACCUMULATED TEMPERATURE ABOVE AND BELOW VARIOUS BASE TEMPERATURES FOR STATIONS IN GREAT BRITAIN AND NORTHERN IRELAND, 1921-50

Introduction.—Accumulated temperature is defined as the integrated excess or deficiency of temperature with reference to a fixed datum, usually called the base temperature, over an extended period of time. Accumulated temperatures with respect to a base temperature of 42°F. are of special interest for agriculture, following the view that this is the critical temperature above which plant growth commences and is maintained in a European climate. For the study of heating and cooling problems, however, engineers are concerned with accumulated temperatures below or above base temperatures in the region of 60-70°F. In this country a base temperature of 60°F. has been adopted for the study of heating problems, it having been shown experimentally that for buildings continuously heated to an internal temperature of 65°F. there is quite a close relation between the amounts of fuel consumed and the accumulated temperatures below 60°F. taken over corresponding periods of time. In American practice, where higher inside temperatures are aimed at, the base temperature usually adopted is 65°F. Heating engineers generally refer to accumulated temperatures as “degree-days”, but strictly speaking the degree-day is the unit in which accumulated temperature is usually expressed.

Averages of accumulated temperature may be derived in a number of ways. Ideally, accurate daily values would be obtained from continuous temperature records, or at least from observations made once hourly; these would then be summed to give monthly values and, given a sufficiently long record, these in turn would be used to compute long-period averages. In practice, daily values are usually evaluated using the method of Meteorological Office Form 3300—“Tables for the Evaluation of Daily Values of Accumulated Temperature above and below 42°F. from Daily Values of Maximum and Minimum Temperature”. The tables can be used for base temperatures other than 42°F. by first suitably adjusting the observed temperature extremes. Daily values obtained in this way may then be combined, as indicated above, to give long-period average monthly values. Averages of accumulated temperature above and below 42°F. for 28 selected stations and for the period 1931-48, computed in this way, have recently been prepared,^{1*} but a good deal of laborious calculation is involved. Earlier averages of accumulated temperature with respect to base 42°F. were computed on a weekly basis using weekly means of daily maximum and minimum temperature by the use of formulae due to Strachey,² but the latest period for which they are available is 1907-26. Accumulated temperatures with respect to any other base have not been computed on a routine basis in the Meteorological Office.

Various methods have been suggested or applied by a number of writers to obtain accumulated temperature averages from monthly mean temperatures or even from long-period average values of monthly mean temperature. Thus, Gregory³ has used averages of monthly mean temperature 1881-1915 to compute averages of accumulated temperature above 42°F. and Dufton⁴ has used the temperature averages for the same period to compute averages of accumulated temperature below 60°F. The results cannot be regarded as satisfactory, however, particularly for months in which the mean temperature is not far removed from the base temperature. In such a case the use of the average monthly mean gives a small or even zero accumulated temperature when it is obvious that on some days the temperature will have been well below or above the base temperature for part, if not all, of the time.

* The index numbers refer to the bibliography on p. 18

Another possible method of computing averages would be to apply the method of Form 3300 using individual monthly values of mean daily maximum and minimum temperature. This more detailed process would clearly be an improvement on any method using average temperatures only because it would take some account of temperature variability. Yet another method is that due to Thom⁵ which by using the standard deviation of monthly mean temperature as well as the long-period average enables a statistical estimate to be made of the additional degree-days in months when use of the average temperature alone would indicate the accumulated temperature to be small or zero. This method has been used in this Note and its use is justified by the comparisons of results obtained by the various methods referred to above which are set out in Tables I and II. Table I shows monthly and annual averages of accumulated temperature above 42°F. for Rothamsted, 1931-48, computed by six different methods, and Table II shows monthly and annual averages below base 60°F. for Kew Observatory, 1950-54, similarly computed. In each case method (i) is the accurate method based on daily values, the figures in Table I being taken from

TABLE I—AVERAGES OF ACCUMULATED TEMPERATURE ABOVE BASE 42°F. (IN DEGREE-DAYS) AT ROTHAMSTED, 1931-48, COMPUTED BY SIX DIFFERENT METHODS

| | Method | | | | | |
|-----------|--------|-------|-------|-------|-------|-------|
| | (i) | (ii) | (iii) | (iv) | (v) | (vi) |
| January | 36 | 12 | 0 | 0 | 0 | 53 |
| February | 40 | 17 | 6 | 3 | 0 | 62 |
| March | 98 | 70 | 53 | 34 | 0 | 115 |
| April | 177 | 162 | 162 | 138 | 131 | 165 |
| May | 319 | 307 | 304 | 305 | 304 | 304 |
| June | 474 | 471 | 471 | 471 | 471 | 471 |
| July | 593 | 592 | 592 | 592 | 592 | 592 |
| August | 589 | 589 | 589 | 589 | 589 | 589 |
| September | 441 | 438 | 438 | 438 | 438 | 438 |
| October | 246 | 225 | 223 | 222 | 223 | 226 |
| November | 100 | 68 | 78 | 43 | 33 | 87 |
| December | 47 | 18 | 9 | 6 | 0 | 59 |
| Year | 3,160 | 2,969 | 2,925 | 2,841 | 2,781 | 3,161 |

- (i) Using daily values of maximum and minimum temperature.
- (ii) Using monthly values of mean daily maximum and mean daily minimum temperature.
- (iii) Using average monthly values of mean daily maximum and mean daily minimum temperature.
- (iv) Using monthly values of mean daily mean temperature [$\frac{1}{2}(\text{max.} + \text{min.})$].
- (v) Using average monthly values of mean daily mean temperature.
- (vi) Using average values of mean daily mean temperature and standard deviation of monthly mean temperature.

unpublished Meteorological Office data¹ and those in Table II from the monthly reports issued by the Gas Council. It is clear that only methods (ii), (iii) and (vi) give comparable results and of these (vi), which is Thom's method, is clearly better than (iii) and slightly better than (ii). Given the standard deviations of monthly mean temperature, which have been computed for a network of stations in the British Isles and are presented in the form of maps in the second part of this Note, Thom's method is also easier to apply than method (ii).

Method used and stations selected.—Thom's expression for the calculation of average monthly accumulated temperature in degree-days below any base b is

$$D = N(b - \bar{t} + l \sqrt{N} \cdot \sigma_m),$$

where N is the number of days in the month, b is the base temperature, \bar{t} is the

TABLE II—AVERAGES OF ACCUMULATED TEMPERATURE BELOW BASE 60°F. (IN DEGREE-DAYS) AT KEW OBSERVATORY, 1950-54, COMPUTED BY SIX DIFFERENT METHODS

| | (i) | (ii) | Method | | (v) | (vi) |
|-----------|-------|-------|--------|-------|-------|-------|
| | | | (iii) | (iv) | | |
| January | 638 | 638 | 637 | 638 | 637 | 637 |
| February | 563 | 566 | 567 | 566 | 567 | 567 |
| March | 498 | 498 | 498 | 498 | 498 | 498 |
| April | 378 | 371 | 372 | 371 | 372 | 372 |
| May | 204 | 182 | 180 | 161 | 161 | 171 |
| June | 88 | 68 | 57 | 22 | 0 | 57 |
| July | 43 | 35 | 34 | 2 | 0 | 37 |
| August | 49 | 39 | 39 | 0 | 0 | 50 |
| September | 133 | 118 | 118 | 94 | 93 | 132 |
| October | 272 | 266 | 267 | 266 | 267 | 267 |
| November | 437 | 437 | 438 | 437 | 438 | 438 |
| December | 567 | 570 | 570 | 570 | 570 | 570 |
| Year | 3,870 | 3,788 | 3,777 | 3,625 | 3,603 | 3,796 |

The six methods are as detailed beneath Table I.

average monthly mean temperature in °F., l is a parameter obtained from a table of l against h where $h = (b - \bar{t}) / (\sqrt{N} \cdot \sigma_m)$, and σ_m is the standard deviation of the monthly mean temperatures. The relation between l and h was established empirically by Thom and shown to be independent of climate and season over the United States. It is therefore fair to assume that the relation will also apply over Great Britain. It can be shown that if averages of accumulated temperature above base b are required then the above expression becomes

$$\bar{D} = N(\bar{t} - b + l \sqrt{N} \cdot \sigma_m).$$

The stations used are those for which values of σ_m and t are available for the standard period 1921-50, the former in Part II of this Note and the latter in a book of averages.⁶ The stations are 49 in number and the computed averages in degree-days below bases of 70°F., 60°F., 50°F., and 42°F. and above bases of 42°F. and 60°F. are presented in Tables IV to IX respectively. Station details (latitude, longitude and height) are given in Table III.

Map of average accumulated temperature below 60°F.—A requirement in connexion with building problems has been the publication in map form of annual averages of accumulated temperature below a base of 60°F. A map has the advantage of presenting the information in a convenient and easily assimilated form, but there are difficulties in drawing a map based on station level averages because of the considerable effects of altitude. Just as average temperature decreases with altitude at a rate of about 1°F. in 300 feet, so average accumulated temperature below 60°F. increases with altitude at a substantial rate. For example, Hampstead (450 feet) has an annual average which is about 12 per cent greater than that for Kew Observatory (18 feet), while Buxton (1,007 feet), has an annual average 15 per cent greater than that at Macclesfield (500 feet). Thus, the map will show the effects of relief quite strongly and will become more complicated as the number of station values is increased, or as appropriate allowances are made for height variations. Nevertheless, an attempt has been made to prepare such a map and it is presented in Figure 1. It shows the broad-scale features of the distribution over the country of annual average accumulated temperature below 60°F. for the period 1921-50. As the values for 49 stations given in Table V were considered too few for the purpose additional values were calculated for most of the remaining stations

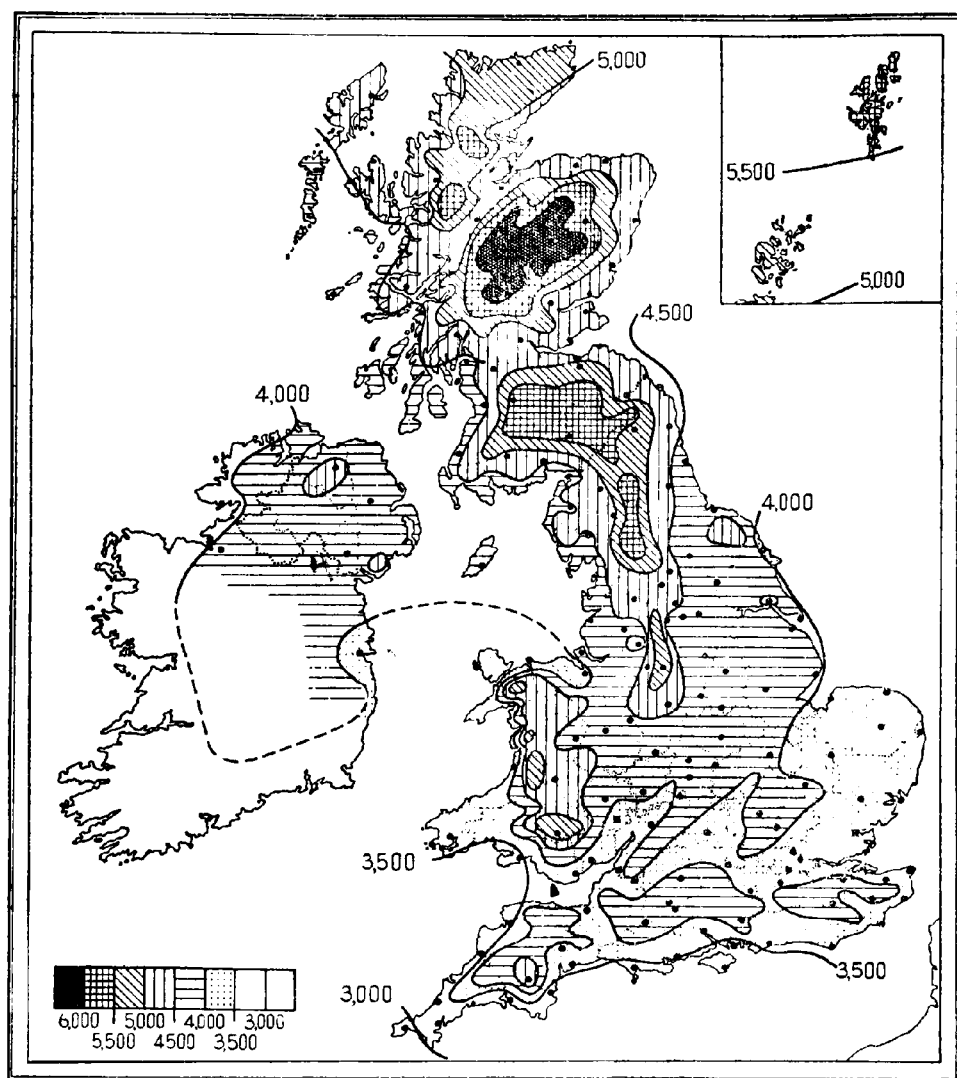


FIGURE 1—AVERAGE ANNUAL ACCUMULATED TEMPERATURE BELOW 60°F. (IN DEGREE-DAYS), 1921-50

TABLE III—POSITIONS AND HEIGHTS OF THE 49 STATIONS MENTIONED
IN TABLES IV TO IX

| Station | Position | | Height | Station | Position | | Height | |
|-------------|----------|------|--------|---------|----------------|---------|--------|-----|
| | ° | ' | feet | | ° | ' | feet | |
| Lerwick | 60 | 8N. | 1 11W. | 269 | Ross-on-Wye | 51 55N. | 2 35W. | 223 |
| Wick | 58 | 27N. | 3 5W. | 119 | Kew | 51 28N. | 0 19W. | 18 |
| Fortrose | 57 | 35N. | 4 8W. | 69 | Wisley | 51 17N. | 0 26W. | 150 |
| Stornoway | 58 | 13N. | 6 20W. | 11 | Dungeness | 50 55N. | 0 58E. | 20 |
| Aberdeen | 57 | 10N. | 2 6W. | 79 | Southampton | 50 55N. | 1 24W. | 65 |
| Braemar | 57 | 0N. | 3 24W. | 1111 | Ventnor | 50 36N. | 1 13W. | 60 |
| Leuchars | 56 | 23N. | 2 53W. | 33 | Marlborough | 51 25N. | 1 44W. | 424 |
| Edinburgh | 55 | 55N. | 3 11W. | 441 | Porton | 51 7N. | 1 42W. | 363 |
| Tiree | 56 | 30N. | 6 53W. | 29 | Keswick | 54 36N. | 3 9W. | 254 |
| Renfrew | 55 | 52N. | 4 26W. | 29 | Manchester | | | |
| Colmonell | 55 | 8N. | 4 57W. | 170 | (Whitworth | | | |
| Eskdalemuir | 55 | 19N. | 3 12W. | 794 | Park) | 53 28N. | 2 14W. | 125 |
| Douglas | 54 | 10N. | 4 28W. | 284 | Southport | 53 37N. | 3 0W. | 35 |
| Cockle Park | 55 | 13N. | 1 41W. | 325 | Stonyhurst | 53 51N. | 2 28W. | 377 |
| Tynemouth | 55 | 1N. | 1 25W. | 108 | Bidston | 53 24N. | 3 4W. | 198 |
| Durham | 54 | 46N. | 1 35W. | 336 | Holyhead | 53 19N. | 4 37W. | 26 |
| York | 53 | 57N. | 1 5W. | 57 | Welshpool | 52 39N. | 3 8W. | 254 |
| Spurn Head | 53 | 35N. | 0 7E. | 29 | St. Ann's Head | 51 41N. | 5 10W. | 142 |
| Gorleston | 52 | 35N. | 1 43E. | 5 | Cardiff | 51 28N. | 3 10W. | 203 |
| Felixstowe | 51 | 57N. | 1 20E. | 10 | Portland Bill | 50 32N. | 2 27W. | 32 |
| Cambridge | 52 | 12N. | 0 8E. | 41 | Shaftesbury | 51 1N. | 2 12W. | 680 |
| Rothamsted | 51 | 48N. | 0 22W. | 420 | Cullompton | 50 51N. | 3 23W. | 202 |
| Sheffield | 53 | 23N. | 1 29W. | 428 | Plymouth | | | |
| Nottingham | 52 | 57N. | 1 9W. | 192 | (Mountbatten) | 50 21N. | 4 7W. | 87 |
| Birmingham | | | | | Scilly | 49 56N. | 6 18W. | 163 |
| (Sparkhill) | 52 | 27N. | 1 51W. | 425 | Armagh | 54 21N. | 6 39W. | 205 |
| Oxford | 51 | 46N. | 1 16W. | 208 | | | | |

for which temperature averages 1921–50 are available, the required standard deviations of monthly mean temperature being interpolated from the maps presented in Part II. To fill some obvious gaps in the network a number of additional temperature averages were computed and weighted to the standard 30-year period. The final map is based on data from 162 stations the positions of which are indicated by dots. Monthly averages of accumulated temperature are also available for each of these stations, but they are not reproduced here.

As previously mentioned the values depend to a considerable extent on altitude and thus the isopleths in Figure 1, drawn at intervals of 500 degree-days, tend to follow the ground contours. With a rather limited station network and such a relatively small-scale map, however, only the larger scale topographical features could be taken into account in drawing the map and it can only be regarded as giving a general picture of the distribution. The average annual number of degree-days below 60°F. varies from just under 3,000 in the extreme south-west of England to 6,000 and over at levels above 1,000 feet in central Scotland, with values of 5,000 and over near sea level in the north of Scotland and the Shetlands. It is probable that the summit of Ben Nevis would have an annual average of rather more than 10,000 degree-days below 60°F.—based on the available averages for the period 1884–1903.

In using Figure 1, there is a danger that values may be interpolated for places which, owing to local topographical features, are at an appreciably different altitude from the nearest meteorological stations used in preparing the map. For example, a value of about 4,400 would be interpolated for the Sheffield area, but this would be too low for a place on the higher ground to the west of

TABLE IV—AVERAGES OF ACCUMULATED TEMPERATURE BELOW 70°F.
(IN DEGREE-DAYS) AT 49 STATIONS, PERIOD 1921-50

| Station | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|----------------|-------|------|-------|-------|-----|------|------|------|-------|------|------|-------|-------|
| Lerwick | 986 | 906 | 961 | 855 | 756 | 615 | 511 | 511 | 582 | 747 | 840 | 936 | 9,206 |
| Wick | 964 | 872 | 911 | 810 | 725 | 570 | 477 | 480 | 537 | 694 | 810 | 915 | 8,765 |
| Fortrose | 970 | 867 | 874 | 738 | 623 | 459 | 363 | 384 | 486 | 676 | 828 | 936 | 8,204 |
| Stornoway | 915 | 833 | 868 | 774 | 676 | 528 | 443 | 443 | 522 | 679 | 786 | 874 | 8,341 |
| Aberdeen | 970 | 869 | 896 | 780 | 679 | 489 | 384 | 412 | 504 | 681 | 822 | 927 | 8,413 |
| Braemar | 1,119 | 999 | 1,001 | 870 | 735 | 540 | 446 | 490 | 600 | 803 | 960 | 1,070 | 9,633 |
| Leuchars | 989 | 878 | 880 | 750 | 648 | 456 | 357 | 384 | 480 | 670 | 834 | 949 | 8,275 |
| Edinburgh | 973 | 881 | 890 | 765 | 648 | 453 | 356 | 384 | 483 | 670 | 816 | 927 | 8,246 |
| Tiree | 880 | 805 | 831 | 723 | 623 | 489 | 419 | 406 | 465 | 608 | 726 | 831 | 7,806 |
| Renfrew | 980 | 867 | 871 | 738 | 607 | 432 | 347 | 369 | 480 | 669 | 840 | 942 | 8,142 |
| Colmonell | 939 | 853 | 859 | 732 | 610 | 450 | 369 | 378 | 465 | 639 | 792 | 902 | 7,988 |
| Eskdalemuir | 1,069 | 965 | 989 | 840 | 701 | 522 | 437 | 465 | 573 | 763 | 915 | 1,029 | 9,259 |
| Douglas | 893 | 827 | 846 | 729 | 608 | 444 | 295 | 369 | 438 | 601 | 735 | 843 | 7,628 |
| Cockle Park | 1,004 | 903 | 908 | 780 | 663 | 471 | 365 | 396 | 489 | 685 | 843 | 964 | 8,471 |
| Tynemouth | 933 | 838 | 852 | 735 | 644 | 447 | 338 | 353 | 429 | 608 | 765 | 889 | 7,831 |
| Durham | 1,001 | 895 | 890 | 750 | 632 | 432 | 325 | 357 | 462 | 663 | 828 | 958 | 8,193 |
| York | 964 | 858 | 843 | 690 | 549 | 357 | 251 | 282 | 399 | 617 | 798 | 933 | 7,541 |
| Spurn Head | 949 | 855 | 862 | 714 | 595 | 399 | 276 | 282 | 363 | 564 | 750 | 902 | 7,511 |
| Gorleston | 933 | 847 | 859 | 705 | 577 | 381 | 263 | 257 | 339 | 549 | 741 | 905 | 7,356 |
| Felixstowe | 946 | 850 | 856 | 687 | 546 | 342 | 220 | 220 | 318 | 536 | 741 | 908 | 7,170 |
| Cambridge | 964 | 861 | 840 | 678 | 524 | 339 | 236 | 258 | 369 | 608 | 795 | 945 | 7,417 |
| Rothamsted | 998 | 895 | 874 | 714 | 564 | 378 | 273 | 295 | 402 | 635 | 825 | 973 | 7,826 |
| Sheffield | 955 | 869 | 853 | 702 | 561 | 369 | 267 | 291 | 402 | 614 | 786 | 918 | 7,587 |
| Nottingham | 958 | 861 | 840 | 681 | 536 | 345 | 249 | 273 | 384 | 611 | 792 | 930 | 7,460 |
| Birmingham | | | | | | | | | | | | | |
| (Sparkhill) | 970 | 869 | 852 | 684 | 536 | 342 | 251 | 279 | 393 | 623 | 801 | 946 | 7,546 |
| Oxford | 945 | 844 | 818 | 660 | 539 | 327 | 238 | 247 | 363 | 576 | 777 | 901 | 7,235 |
| Ross-on-Wye | 918 | 830 | 818 | 669 | 533 | 345 | 261 | 282 | 387 | 601 | 765 | 899 | 7,308 |
| Kew | 927 | 836 | 812 | 651 | 487 | 294 | 204 | 231 | 348 | 583 | 765 | 905 | 7,043 |
| Wisley | 942 | 844 | 818 | 660 | 502 | 321 | 220 | 241 | 360 | 591 | 806 | 897 | 7,202 |
| Dungeness | 915 | 836 | 846 | 690 | 555 | 372 | 267 | 248 | 327 | 524 | 714 | 884 | 7,178 |
| Southampton | 905 | 813 | 800 | 642 | 487 | 306 | 229 | 234 | 339 | 555 | 735 | 884 | 6,929 |
| Ventnor | 846 | 785 | 778 | 636 | 496 | 324 | 239 | 226 | 297 | 483 | 663 | 815 | 6,588 |
| Marlborough | 980 | 875 | 868 | 717 | 573 | 387 | 298 | 322 | 432 | 651 | 822 | 958 | 7,883 |
| Porton | 977 | 875 | 859 | 705 | 561 | 375 | 285 | 301 | 405 | 626 | 810 | 955 | 7,734 |
| Keswick | 942 | 858 | 856 | 729 | 586 | 411 | 325 | 347 | 456 | 642 | 792 | 908 | 7,852 |
| Manchester | | | | | | | | | | | | | |
| (Whitworth | | | | | | | | | | | | | |
| Park) | 930 | 841 | 821 | 675 | 527 | 345 | 264 | 289 | 393 | 605 | 777 | 908 | 7,375 |
| Southport | 942 | 847 | 840 | 693 | 561 | 384 | 288 | 307 | 405 | 608 | 777 | 905 | 7,557 |
| Stonyhurst | 986 | 892 | 883 | 735 | 583 | 408 | 322 | 344 | 451 | 651 | 819 | 945 | 8,019 |
| Bidston | 930 | 847 | 843 | 699 | 561 | 384 | 298 | 313 | 408 | 608 | 765 | 893 | 7,549 |
| Holyhead | 837 | 779 | 797 | 687 | 579 | 423 | 338 | 322 | 381 | 539 | 675 | 791 | 7,148 |
| Welshpool | 958 | 862 | 856 | 702 | 561 | 387 | 298 | 319 | 429 | 642 | 807 | 921 | 7,742 |
| St. Ann's Head | 812 | 771 | 796 | 687 | 579 | 420 | 341 | 319 | 378 | 524 | 654 | 769 | 7,050 |
| Cardiff | 911 | 827 | 812 | 666 | 527 | 345 | 267 | 276 | 375 | 580 | 747 | 880 | 7,213 |
| Portland Bill | 806 | 768 | 802 | 678 | 558 | 387 | 304 | 267 | 318 | 477 | 630 | 769 | 6,764 |
| Shaftesbury | 964 | 875 | 859 | 708 | 573 | 387 | 303 | 310 | 408 | 617 | 795 | 939 | 7,738 |
| Cullompton | 902 | 813 | 797 | 648 | 502 | 318 | 242 | 267 | 372 | 583 | 756 | 887 | 7,087 |
| Plymouth | | | | | | | | | | | | | |
| (Mountbatten) | 818 | 759 | 756 | 627 | 502 | 330 | 266 | 267 | 336 | 512 | 675 | 800 | 6,648 |
| Scilly | 735 | 686 | 710 | 630 | 536 | 378 | 295 | 273 | 330 | 477 | 600 | 707 | 6,357 |
| Armagh | 924 | 824 | 828 | 711 | 564 | 408 | 338 | 357 | 456 | 639 | 789 | 896 | 7,734 |

the city and too high for the city itself; the actual value for the Sheffield climatological station is 4,170, and this comparatively low value probably reflects the warming effect of the built-up area.

When preparing average temperature maps it is customary to first reduce the station values to mean sea level by adding a correction of 1°F. for each 300 feet of altitude. This simplifies the resulting map by eliminating the effects of altitude, but it must be remembered that in using the map to interpolate values for

TABLE V—AVERAGES OF ACCUMULATED TEMPERATURE BELOW 60°F.
(IN DEGREE-DAYS) AT 49 STATIONS, PERIOD 1921-50

| Station | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|----------------|------|------|-------|-------|-----|------|------|------|-------|------|------|------|-------|
| Lerwick | 676 | 624 | 651 | 555 | 446 | 315 | 204 | 205 | 282 | 437 | 540 | 626 | 5,561 |
| Wick | 654 | 590 | 601 | 510 | 415 | 270 | 170 | 176 | 237 | 384 | 510 | 605 | 5,122 |
| Fortrose | 660 | 584 | 564 | 438 | 313 | 171 | 84 | 102 | 192 | 366 | 528 | 626 | 4,628 |
| Stornoway | 605 | 551 | 558 | 474 | 366 | 228 | 140 | 141 | 225 | 369 | 486 | 564 | 4,707 |
| Aberdeen | 660 | 587 | 586 | 480 | 369 | 192 | 90 | 119 | 204 | 370 | 522 | 617 | 4,796 |
| Braemar | 809 | 717 | 704 | 570 | 425 | 243 | 149 | 189 | 300 | 493 | 660 | 760 | 6,019 |
| Leuchars | 679 | 596 | 570 | 450 | 338 | 165 | 74 | 96 | 186 | 360 | 534 | 639 | 4,687 |
| Edinburgh | 663 | 598 | 580 | 465 | 338 | 165 | 74 | 102 | 183 | 360 | 516 | 617 | 4,661 |
| Tiree | 570 | 522 | 521 | 423 | 313 | 189 | 112 | 102 | 168 | 298 | 426 | 521 | 4,165 |
| Renfrew | 670 | 584 | 561 | 438 | 298 | 153 | 74 | 95 | 189 | 359 | 540 | 632 | 4,593 |
| Colmonell | 629 | 570 | 549 | 432 | 301 | 156 | 87 | 87 | 171 | 329 | 492 | 592 | 4,395 |
| Eskdalemuir | 759 | 683 | 670 | 540 | 391 | 225 | 143 | 167 | 273 | 453 | 615 | 719 | 5,638 |
| Douglas | 583 | 545 | 536 | 429 | 298 | 156 | 92 | 93 | 146 | 291 | 435 | 533 | 4,137 |
| Cockle Park | 694 | 621 | 598 | 480 | 353 | 177 | 89 | 116 | 195 | 375 | 543 | 654 | 4,895 |
| Tynemouth | 623 | 556 | 542 | 435 | 335 | 151 | 62 | 77 | 141 | 298 | 465 | 579 | 4,264 |
| Durham | 691 | 613 | 580 | 450 | 322 | 148 | 68 | 89 | 172 | 353 | 528 | 648 | 4,662 |
| York | 654 | 576 | 533 | 390 | 242 | 96 | 40 | 54 | 122 | 307 | 498 | 623 | 4,135 |
| Spurn Head | 639 | 573 | 552 | 414 | 285 | 116 | 26 | 36 | 99 | 254 | 450 | 592 | 4,036 |
| Gorleston | 623 | 565 | 549 | 405 | 267 | 155 | 20 | 36 | 79 | 239 | 441 | 595 | 3,974 |
| Felixstowe | 635 | 567 | 546 | 387 | 235 | 81 | 16 | 22 | 81 | 233 | 441 | 598 | 3,842 |
| Cambridge | 654 | 579 | 530 | 378 | 217 | 78 | 36 | 46 | 111 | 298 | 495 | 635 | 4,057 |
| Rothamsted | 688 | 613 | 564 | 414 | 258 | 100 | 49 | 64 | 137 | 325 | 525 | 663 | 4,400 |
| Sheffield | 645 | 587 | 543 | 402 | 255 | 107 | 51 | 57 | 125 | 304 | 486 | 608 | 4,170 |
| Nottingham | 648 | 579 | 530 | 381 | 230 | 88 | 45 | 54 | 115 | 301 | 492 | 620 | 4,083 |
| Birmingham | | | | | | | | | | | | | |
| (Sparkhill) | 660 | 587 | 542 | 384 | 229 | 84 | 47 | 56 | 120 | 313 | 501 | 636 | 4,159 |
| Oxford | 635 | 562 | 508 | 360 | 208 | 71 | 36 | 44 | 106 | 285 | 477 | 611 | 3,903 |
| Ross-on-Wye | 608 | 548 | 508 | 369 | 226 | 79 | 49 | 51 | 112 | 291 | 465 | 589 | 3,895 |
| Kew | 617 | 553 | 502 | 351 | 187 | 56 | 27 | 39 | 103 | 273 | 465 | 595 | 3,768 |
| Wisley | 632 | 562 | 508 | 360 | 198 | 66 | 37 | 47 | 109 | 282 | 480 | 616 | 3,897 |
| Dungeness | 605 | 553 | 536 | 390 | 245 | 85 | 29 | 24 | 82 | 230 | 414 | 574 | 3,767 |
| Southampton | 595 | 531 | 490 | 342 | 182 | 59 | 37 | 38 | 90 | 249 | 435 | 574 | 3,622 |
| Ventnor | 536 | 502 | 468 | 336 | 188 | 63 | 34 | 31 | 66 | 183 | 363 | 505 | 3,275 |
| Marlborough | 670 | 593 | 558 | 417 | 263 | 105 | 62 | 68 | 153 | 341 | 522 | 648 | 4,400 |
| Porton | 667 | 592 | 549 | 405 | 251 | 99 | 56 | 65 | 135 | 316 | 510 | 645 | 4,290 |
| Keswick | 632 | 576 | 546 | 429 | 275 | 143 | 65 | 81 | 168 | 332 | 492 | 598 | 4,337 |
| Manchester | | | | | | | | | | | | | |
| (Whitworth | | | | | | | | | | | | | |
| Park) | 620 | 559 | 511 | 375 | 220 | 90 | 52 | 66 | 125 | 295 | 477 | 598 | 3,988 |
| Southport | 632 | 565 | 530 | 393 | 251 | 103 | 46 | 56 | 118 | 298 | 477 | 595 | 4,064 |
| Stonyhurst | 676 | 610 | 573 | 435 | 273 | 131 | 68 | 83 | 154 | 341 | 519 | 635 | 4,498 |
| Bidston | 620 | 565 | 533 | 399 | 251 | 103 | 60 | 65 | 123 | 298 | 465 | 583 | 4,065 |
| Holyhead | 527 | 497 | 487 | 387 | 269 | 126 | 65 | 59 | 100 | 229 | 375 | 481 | 3,602 |
| Welshpool | 648 | 579 | 528 | 402 | 251 | 117 | 65 | 74 | 144 | 332 | 507 | 611 | 4,258 |
| St. Ann's Head | 502 | 488 | 486 | 387 | 270 | 129 | 77 | 58 | 97 | 242 | 354 | 458 | 3,548 |
| Cardiff | 601 | 545 | 502 | 366 | 217 | 87 | 49 | 53 | 108 | 270 | 449 | 570 | 3,817 |
| Portland Bill | 496 | 486 | 492 | 378 | 248 | 102 | 49 | 37 | 60 | 180 | 339 | 459 | 3,326 |
| Shaftesbury | 654 | 592 | 549 | 408 | 263 | 114 | 71 | 65 | 138 | 307 | 495 | 629 | 4,285 |
| Cullompton | 592 | 531 | 487 | 348 | 194 | 69 | 37 | 46 | 103 | 273 | 456 | 576 | 3,712 |
| Plymouth | | | | | | | | | | | | | |
| (Mountbatten) | 508 | 477 | 446 | 327 | 194 | 75 | 49 | 43 | 87 | 208 | 375 | 490 | 3,279 |
| Scilly | 425 | 404 | 400 | 330 | 226 | 96 | 53 | 45 | 75 | 171 | 300 | 397 | 2,922 |
| Armagh | 614 | 542 | 518 | 411 | 254 | 126 | 72 | 84 | 165 | 329 | 489 | 586 | 4,190 |

a specific place, a reverse correction must be applied, depending on the altitude of the place. The same thing can be done for accumulated temperature and Figure 2 shows the distribution of average annual accumulated temperature below 60°F. computed by Thom's formula after first reducing the temperature averages for the 162 stations to mean sea level. The pattern is considerably less complicated than that of Figure 1, although isopleths at intervals of 250 degree-days are drawn; the main features remaining are the general increase

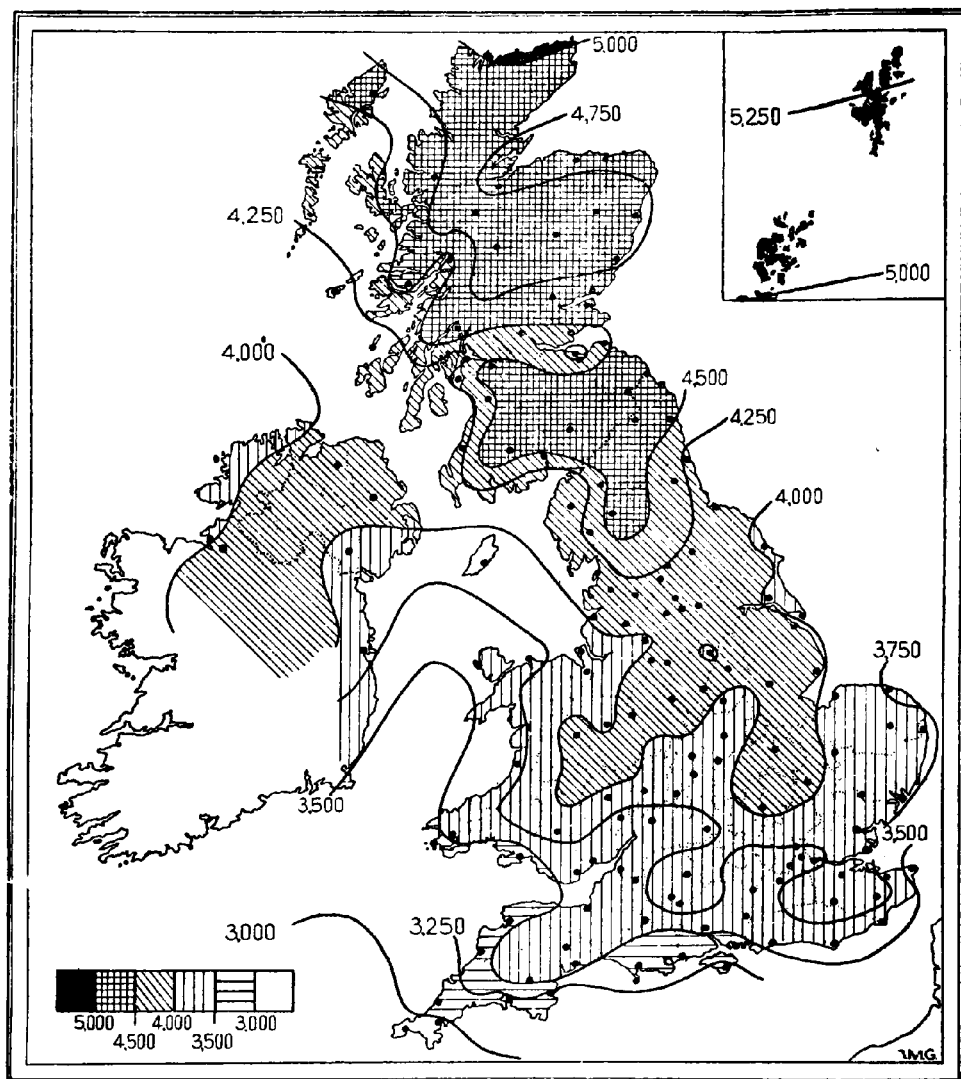


FIGURE 2—AVERAGE ANNUAL ACCUMULATED TEMPERATURE BELOW 60°F. (IN DEGREE-DAYS), 1921-50, REDUCED TO MEAN SEA LEVEL

TABLE VI—AVERAGES OF ACCUMULATED TEMPERATURE BELOW 50°F.
(IN DEGREE-DAYS) AT 49 STATIONS, PERIOD 1921-50

| Station | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|----------------|------|------|-------|-------|-----|------|------|------|-------|------|------|------|-------|
| Lerwick | 366 | 342 | 346 | 255 | 141 | 68 | 13 | 19 | 43 | 144 | 240 | 316 | 2,293 |
| Wick | 344 | 308 | 301 | 213 | 115 | 30 | | 6 | 18 | 99 | 213 | 295 | 1,942 |
| Fortrose | 353 | 305 | 270 | 153 | 62 | 12 | | | | 90 | 234 | 319 | 1,798 |
| Stornoway | 298 | 268 | 256 | 180 | 82 | 26 | | 3 | 27 | 93 | 192 | 263 | 1,688 |
| Aberdeen | 350 | 309 | 292 | 192 | 87 | 15 | | | | 3 | 90 | 229 | 1,878 |
| Braemar | 499 | 435 | 431 | 273 | 130 | 42 | 6 | 21 | 63 | 192 | 360 | 456 | 2,908 |
| Leuchars | 375 | 319 | 276 | 168 | 65 | 12 | | | 12 | 87 | 237 | 332 | 1,883 |
| Edinburgh | 366 | 322 | 285 | 180 | 80 | 15 | | | 15 | 93 | 219 | 313 | 1,888 |
| Tiree | 264 | 246 | 223 | 130 | 28 | 6 | | | 3 | 37 | 132 | 217 | 1,286 |
| Renfrew | 378 | 308 | 267 | 156 | 50 | 12 | | | 18 | 96 | 243 | 332 | 1,760 |
| Colmonell | 338 | 296 | 251 | 144 | 37 | 3 | | | 3 | 69 | 198 | 291 | 1,630 |
| Eskdalemuir | 449 | 401 | 366 | 243 | 99 | 27 | 3 | 9 | 51 | 155 | 315 | 409 | 2,527 |
| Douglas | 282 | 265 | 233 | 141 | 31 | 3 | | | 3 | 37 | 147 | 232 | 1,375 |
| Cockle Park | 389 | 343 | 304 | 192 | 74 | 18 | | 3 | 21 | 93 | 243 | 347 | 2,027 |
| Tynemouth | 317 | 283 | 252 | 158 | 71 | | | | 2 | 50 | 258 | 310 | 1,701 |
| Durham | 387 | 335 | 285 | 174 | 65 | 7 | | | 17 | 84 | 231 | 343 | 1,928 |
| York | 363 | 304 | 243 | 124 | 31 | | | | 2 | 63 | 209 | 318 | 1,657 |
| Spurn Head | 333 | 301 | 256 | 133 | 42 | | | | | 37 | 158 | 287 | 1,547 |
| Gorleston | 324 | 292 | 253 | 129 | 31 | | | | | 29 | 154 | 295 | 1,507 |
| Felixstowe | 335 | 302 | 248 | 117 | 25 | | | | | 34 | 159 | 298 | 1,518 |
| Cambridge | 363 | 314 | 233 | 116 | 25 | | | | | 60 | 206 | 336 | 1,653 |
| Rothamsted | 391 | 342 | 284 | 140 | 39 | | | | 10 | 71 | 232 | 359 | 1,868 |
| Sheffield | 347 | 322 | 254 | 137 | 41 | 4 | | | 3 | 63 | 193 | 307 | 1,671 |
| Nottingham | 350 | 333 | 239 | 120 | 28 | | | | 5 | 56 | 203 | 320 | 1,654 |
| Birmingham | | | | | | | | | | | | | |
| (Sparkhill) | 369 | 322 | 245 | 123 | 31 | | | | 3 | 53 | 213 | 335 | 1,694 |
| Oxford | 343 | 304 | 214 | 105 | 21 | | | | 4 | 52 | 198 | 310 | 1,551 |
| Ross-on-Wye | 324 | 289 | 215 | 111 | 22 | | | | 2 | 57 | 186 | 295 | 1,501 |
| Kew | 325 | 288 | 209 | 100 | 18 | | | | 3 | 45 | 180 | 295 | 1,463 |
| Wisley | 341 | 302 | 214 | 105 | 19 | | | | 2 | 56 | 201 | 316 | 1,556 |
| Dungeness | 319 | 285 | 233 | 117 | 26 | | | | | 25 | 144 | 279 | 1,428 |
| Southampton | 310 | 271 | 195 | 93 | 6 | | | | | 43 | 154 | 279 | 1,351 |
| Ventnor | 254 | 246 | 178 | 75 | 6 | | | | | 19 | 108 | 220 | 1,106 |
| Marlborough | 372 | 321 | 257 | 141 | 33 | | | | 12 | 81 | 234 | 347 | 1,798 |
| Porton | 369 | 327 | 248 | 108 | 29 | | | | 9 | 68 | 222 | 341 | 1,721 |
| Keswick | 341 | 302 | 248 | 150 | 43 | 6 | | | 21 | 80 | 219 | 310 | 1,720 |
| Manchester | | | | | | | | | | | | | |
| (Whitworth | | | | | | | | | | | | | |
| Park) | 328 | 292 | 225 | 109 | 22 | | | | 5 | 60 | 192 | 298 | 1,531 |
| Southport | 341 | 292 | 232 | 119 | 23 | | | | | 57 | 192 | 295 | 1,551 |
| Stonyhurst | 371 | 332 | 272 | 157 | 42 | 3 | | | 9 | 18 | 226 | 330 | 1,760 |
| Bidston | 328 | 292 | 236 | 128 | 27 | | | | 3 | 56 | 175 | 282 | 1,527 |
| Holyhead | 235 | 225 | 186 | 105 | 19 | | | | | 19 | 99 | 178 | 1,066 |
| Welshpool | 357 | 314 | 248 | 126 | 28 | 6 | | | 6 | 84 | 219 | 310 | 1,698 |
| St. Ann's Head | 213 | 225 | 183 | 102 | 21 | | | | | 15 | 86 | 173 | 1,018 |
| Cardiff | 307 | 284 | 313 | 69 | 20 | | | | 3 | 49 | 165 | 275 | 1,485 |
| Portland Bill | 217 | 228 | 189 | 102 | 19 | | | | | 12 | 117 | 183 | 1,067 |
| Shaftesbury | 356 | 327 | 248 | 129 | 41 | 3 | | | 9 | 65 | 207 | 319 | 1,704 |
| Cullompton | 307 | 271 | 192 | 96 | 9 | | | | | 43 | 180 | 282 | 1,380 |
| Plymouth | | | | | | | | | | | | | |
| (Mountbatten) | 229 | 220 | 155 | 75 | 9 | | | | | 18 | 111 | 208 | 1,025 |
| Scilly | 140 | 141 | 105 | 60 | 9 | | | | | 6 | 54 | 118 | 633 |
| Armagh | 313 | 268 | 226 | 114 | 28 | 4 | | | 6 | 87 | 198 | 285 | 1,529 |

Where no figure is given, the average is zero

from less than 3,000 degree-days in the extreme south-west to 5,000 or over in the extreme north and the tendency for higher values as one goes inland from the coasts. It is considered that Figure 2 can be used to interpolate average values for places at or near sea level, probably up to about 100 feet, without serious error. Unfortunately there is no simple way of applying a correction for altitude as in the case of average temperature because the correction is not simply related to altitude. Comparison between the station-level values and

TABLE VII—AVERAGES OF ACCUMULATED TEMPERATURE BELOW 42°F.
(IN DEGREE-DAYS) AT 49 STATIONS, PERIOD 1921-50

| Station | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|-----------------------------------|------|------|-------|-------|-----|------|------|------|-------|------|------|------|-------|
| Lerwick | 144 | 136 | 144 | 57 | 7 | | | | | 20 | 56 | 116 | 680 |
| Wick | 127 | 116 | 124 | 105 | 3 | | | | | | 48 | 99 | 622 |
| Fortrose | 174 | 121 | 105 | 24 | | | | | | 4 | 57 | 124 | 609 |
| Stornoway | 99 | 85 | 79 | 33 | 27 | | | | | 3 | 36 | 85 | 447 |
| Aberdeen | 146 | 126 | 119 | 45 | | | | | | 3 | 58 | 113 | 610 |
| Braemar | 189 | 236 | 152 | 87 | 12 | | | | | 40 | 141 | 236 | 1,093 |
| Leuchars | 164 | 138 | 109 | 39 | | | | | | | 60 | 130 | 640 |
| Edinburgh | 164 | 141 | 111 | 36 | | | | | | | 51 | 121 | 624 |
| Tiree | 81 | 79 | 62 | 6 | | | | | | | 6 | 49 | 283 |
| Renfrew | 177 | 133 | 99 | 24 | | | | | | 9 | 60 | 142 | 644 |
| Colmonell | 155 | 121 | 78 | 18 | | | | | | | 39 | 105 | 516 |
| Eskdalemuir | 236 | 203 | 161 | 69 | 3 | | | | | 22 | 108 | 195 | 997 |
| Douglas | 102 | 93 | 65 | 12 | | | | | | | 18 | 65 | 355 |
| Cockle Park | 176 | 155 | 124 | 45 | | | | | | | 60 | 139 | 699 |
| Tynemouth | 124 | 115 | 90 | 30 | | | | | | | 30 | 72 | 461 |
| Durham | 183 | 161 | 110 | 40 | | | | | | 3 | 60 | 141 | 698 |
| York | 177 | 136 | 85 | 20 | | | | | | | 52 | 196 | 666 |
| Spurn Head | 130 | 129 | 87 | 18 | | | | | | | 19 | 94 | 477 |
| Gorleston | 140 | 124 | 84 | 17 | | | | | | | 23 | 112 | 500 |
| Felixstowe | 149 | 138 | 81 | 18 | | | | | | | 30 | 112 | 528 |
| Cambridge | 179 | 152 | 75 | 16 | | | | | | | 52 | 147 | 621 |
| Rothamsted | 192 | 169 | 121 | 25 | 8 | | | | | | 64 | 162 | 741 |
| Sheffield | 163 | 151 | 96 | 23 | | | | | | | 42 | 122 | 597 |
| Nottingham | 168 | 143 | 79 | 18 | | | | | | | 54 | 135 | 597 |
| Birmingham (Sparkhill) | 179 | 155 | 78 | 18 | | | | | | | 54 | 143 | 627 |
| Oxford | 170 | 146 | 63 | 13 | | | | | | | 52 | 133 | 577 |
| Ross-on-Wye | 155 | 136 | 58 | 14 | | | | | | | 48 | 122 | 533 |
| Kew | 149 | 133 | 56 | 11 | | | | | | | 42 | 152 | 543 |
| Wisley | 164 | 141 | 58 | 12 | | | | | | | 55 | 130 | 560 |
| Dungeness | 146 | 127 | 62 | 15 | | | | | | | 27 | 112 | 489 |
| Southampton | 140 | 117 | 47 | 9 | | | | | | | 28 | 109 | 450 |
| Ventnor | 100 | 97 | 31 | 3 | | | | | | | 12 | 37 | 280 |
| Marlborough | 189 | 158 | 77 | 24 | | | | | | 3 | 75 | 151 | 677 |
| Porton | 183 | 161 | 71 | 24 | | | | | | | 69 | 146 | 654 |
| Keswick | 161 | 130 | 84 | 23 | | | | | | 4 | 54 | 127 | 583 |
| Manchester (Whitworth Park) | 153 | 130 | 70 | 11 | | | | | | | 47 | 120 | 531 |
| Southport | 159 | 126 | 63 | 13 | | | | | | | 39 | 117 | 517 |
| Stonyhurst | 140 | 150 | 89 | 28 | | | | | | 3 | 62 | 137 | 609 |
| Bidston | 144 | 126 | 74 | 17 | | | | | | | 34 | 107 | 502 |
| Holyhead | 78 | 79 | 34 | 3 | | | | | | | 3 | 47 | 244 |
| Welshpool | 177 | 150 | 81 | 18 | | | | | | 3 | 66 | 130 | 625 |
| St. Ann's Head | 68 | 82 | 31 | 2 | | | | | | | | 43 | 226 |
| Cardiff | 133 | 127 | 49 | 15 | | | | | | | 36 | 102 | 462 |
| Portland Bill | 73 | 87 | 31 | 3 | | | | | | | 24 | 50 | 268 |
| Shaftesbury | 164 | 158 | 65 | 147 | | | | | | 3 | 48 | 136 | 721 |
| Cullompton | 136 | 113 | 37 | 120 | | | | | | | 42 | 105 | 553 |
| Plymouth (Mountbatten) | 28 | 82 | 22 | 3 | | | | | | | 13 | 68 | 216 |
| Scilly | 22 | 25 | 3 | | | | | | | | | 16 | 66 |
| Armagh | 130 | 101 | 68 | 27 | | | | | | | 45 | 105 | 476 |

Where no figure is given, the average is zero

sea-level values which have been computed suggests that for annual averages the correction ranges from about 1.0 degree-days per foot in southern England to about 1.2 degree-days per foot in southern Scotland and the Shetlands. Thus the addition of 365 degree-days for every 300 feet increase in altitude (just over 1.2 degree-days per foot) is too large a correction except in those months when the mean temperature is well below the base temperature or in the

TABLE VIII—AVERAGES OF ACCUMULATED TEMPERATURE ABOVE 42°F.
(IN DEGREE-DAYS) AT 49 STATIONS, PERIOD 1921-50

| Station | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|----------------|------|------|-------|-------|-----|------|------|------|-------|------|------|------|-------|
| Lerwick | 26 | 25 | 51 | 43 | 118 | 228 | 357 | 357 | 258 | 141 | 56 | 47 | 1,706 |
| Wick | 31 | 36 | 76 | 75 | 147 | 270 | 391 | 387 | 303 | 179 | 77 | 53 | 2,025 |
| Fortrose | 73 | 45 | 97 | 125 | 245 | 381 | 505 | 484 | 354 | 198 | 62 | 58 | 2,627 |
| Stornoway | 53 | 48 | 76 | 96 | 123 | 312 | 425 | 425 | 318 | 195 | 90 | 55 | 2,216 |
| Aberdeen | 46 | 48 | 90 | 103 | 192 | 351 | 484 | 456 | 336 | 192 | 74 | 53 | 2,425 |
| Braemar | 33 | 28 | 64 | 57 | 145 | 300 | 422 | 378 | 243 | 103 | 21 | 39 | 1,833 |
| Leuchars | 43 | 52 | 95 | 124 | 220 | 384 | 511 | 484 | 360 | 205 | 66 | 54 | 2,598 |
| Edinburgh | 60 | 49 | 95 | 111 | 220 | 387 | 511 | 484 | 363 | 205 | 74 | 67 | 2,626 |
| Tiree | 68 | 69 | 100 | 124 | 245 | 351 | 449 | 462 | 375 | 260 | 121 | 85 | 2,709 |
| Renfrew | 70 | 59 | 92 | 126 | 260 | 408 | 521 | 499 | 360 | 209 | 63 | 65 | 2,732 |
| Colmonell | 85 | 64 | 87 | 126 | 257 | 390 | 499 | 490 | 375 | 229 | 89 | 81 | 2,772 |
| Eskdalemuir | 31 | 25 | 47 | 69 | 171 | 318 | 431 | 403 | 267 | 124 | 33 | 34 | 1,953 |
| Douglas | 78 | 60 | 86 | 125 | 260 | 396 | 496 | 499 | 402 | 267 | 122 | 92 | 2,883 |
| Cockle Park | 43 | 45 | 87 | 102 | 205 | 369 | 502 | 471 | 351 | 189 | 57 | 47 | 2,468 |
| Tynemouth | 60 | 65 | 105 | 135 | 226 | 393 | 530 | 515 | 411 | 260 | 103 | 70 | 2,873 |
| Durham | 54 | 54 | 92 | 129 | 239 | 408 | 543 | 511 | 378 | 208 | 74 | 50 | 2,740 |
| York | 77 | 73 | 109 | 168 | 319 | 483 | 617 | 582 | 441 | 254 | 93 | 65 | 3,281 |
| Spurn Head | 54 | 69 | 95 | 143 | 273 | 441 | 592 | 586 | 477 | 304 | 109 | 61 | 3,204 |
| Gorleston | 74 | 68 | 93 | 152 | 291 | 459 | 605 | 611 | 501 | 319 | 121 | 74 | 3,368 |
| Felixstowe | 72 | 79 | 93 | 161 | 384 | 498 | 648 | 648 | 522 | 332 | 128 | 71 | 3,636 |
| Cambridge | 84 | 82 | 105 | 180 | 344 | 501 | 636 | 614 | 471 | 261 | 93 | 68 | 3,439 |
| Rothamsted | 68 | 71 | 115 | 152 | 304 | 462 | 595 | 573 | 438 | 236 | 76 | 55 | 3,145 |
| Sheffield | 77 | 71 | 112 | 162 | 307 | 471 | 605 | 577 | 438 | 258 | 94 | 71 | 3,243 |
| Nottingham | 79 | 80 | 107 | 179 | 332 | 495 | 626 | 598 | 456 | 257 | 97 | 73 | 3,379 |
| Birmingham | | | | | | | | | | | | | |
| (Sparkhill) | 83 | 79 | 96 | 175 | 332 | 498 | 623 | 592 | 447 | 248 | 96 | 68 | 3,337 |
| Oxford | 93 | 96 | 112 | 195 | 356 | 513 | 645 | 623 | 477 | 273 | 117 | 81 | 3,581 |
| Ross-on-Wye | 108 | 99 | 108 | 186 | 335 | 495 | 611 | 586 | 453 | 267 | 120 | 92 | 3,460 |
| Kew | 93 | 87 | 109 | 201 | 381 | 546 | 676 | 644 | 492 | 285 | 117 | 78 | 3,709 |
| Wisley | 90 | 87 | 108 | 195 | 366 | 519 | 648 | 626 | 480 | 276 | 115 | 73 | 3,583 |
| Dungeness | 97 | 77 | 83 | 163 | 313 | 468 | 601 | 620 | 513 | 344 | 154 | 97 | 3,530 |
| Southampton | 102 | 99 | 115 | 210 | 381 | 534 | 644 | 642 | 501 | 313 | 135 | 93 | 3,769 |
| Ventnor | 116 | 103 | 122 | 207 | 372 | 516 | 632 | 648 | 543 | 384 | 188 | 120 | 3,951 |
| Marlborough | 73 | 71 | 79 | 145 | 295 | 453 | 570 | 546 | 408 | 223 | 91 | 66 | 3,020 |
| Porton | 72 | 73 | 78 | 158 | 307 | 465 | 583 | 567 | 435 | 245 | 99 | 58 | 3,140 |
| Keswick | 87 | 62 | 96 | 135 | 282 | 429 | 543 | 521 | 384 | 230 | 97 | 83 | 2,949 |
| Manchester | | | | | | | | | | | | | |
| (Whitworth | | | | | | | | | | | | | |
| Park) | 89 | 80 | 116 | 179 | 341 | 495 | 608 | 583 | 447 | 263 | 108 | 79 | 3,388 |
| Southport | 84 | 68 | 90 | 159 | 307 | 456 | 579 | 561 | 435 | 267 | 108 | 77 | 3,191 |
| Stonyhurst | 53 | 52 | 79 | 134 | 285 | 432 | 546 | 524 | 387 | 220 | 82 | 67 | 2,861 |
| Bidston | 85 | 67 | 98 | 159 | 307 | 456 | 570 | 555 | 432 | 260 | 108 | 82 | 3,179 |
| Holyhead | 105 | 89 | 104 | 161 | 288 | 417 | 530 | 546 | 459 | 329 | 171 | 121 | 3,320 |
| Welshpool | 87 | 79 | 93 | 153 | 307 | 453 | 570 | 549 | 411 | 233 | 99 | 77 | 3,111 |
| St. Ann's Head | 123 | 99 | 102 | 158 | 288 | 420 | 527 | 549 | 462 | 344 | 192 | 142 | 3,406 |
| Cardiff | 94 | 87 | 105 | 189 | 341 | 495 | 601 | 592 | 465 | 288 | 127 | 87 | 3,471 |
| Portland Bill | 135 | 110 | 96 | 167 | 310 | 453 | 564 | 601 | 522 | 391 | 235 | 146 | 3,730 |
| Shaftesbury | 69 | 75 | 84 | 149 | 295 | 453 | 567 | 558 | 432 | 255 | 95 | 64 | 3,096 |
| Cullompton | 105 | 96 | 111 | 203 | 366 | 522 | 629 | 605 | 468 | 285 | 137 | 95 | 3,622 |
| Plymouth | | | | | | | | | | | | | |
| (Mountbatten) | 127 | 115 | 136 | 216 | 366 | 510 | 605 | 608 | 504 | 357 | 179 | 133 | 3,856 |
| Scilly | 156 | 128 | 163 | 210 | 332 | 462 | 573 | 595 | 510 | 391 | 240 | 175 | 3,935 |
| Armagh | 68 | 68 | 109 | 159 | 285 | 432 | 530 | 511 | 384 | 229 | 93 | 74 | 2,942 |

extreme north, where even the summer monthly mean temperatures are sufficiently far below 60°F. A more accurate method of estimating accumulated temperature averages for a place which is neither near sea level nor near a meteorological station is described in the next section.

Estimation of averages of accumulated temperature below 60°F.—Suppose that it is desired to estimate the average accumulated temperature below 60°F.

TABLE IX—AVERAGES OF ACCUMULATED TEMPERATURE ABOVE 60°F.
(IN DEGREE-DAYS) AT 49 STATIONS, PERIOD 1921-50

| Station | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. | Year |
|----------------|------|------|-------|-------|-----|------|------|------|-------|------|------|------|------|
| Lerwick | | | | | | | 3 | 3 | | | | | 3 |
| Wick | | | | | | | 3 | 3 | | | | | 6 |
| Fortrose | | | | | 9 | 31 | 31 | | 3 | | | | 74 |
| Stornoway | | | | | | 6 | 6 | | | | | | 12 |
| Aberdeen | | | | 3 | 19 | 15 | | | | | | | 37 |
| Braemar | | | | | 12 | 6 | | | | | | | 18 |
| Leuchars | | | | 9 | 25 | 25 | | 3 | | | | | 62 |
| Edinburgh | | | | 12 | 31 | 31 | | 3 | | | | | 77 |
| Tiree | | | | | | 3 | 3 | | | | | | 6 |
| Renfrew | | | | 21 | 37 | 40 | | 6 | | | | | 104 |
| Colmonell | | | | 3 | 31 | 19 | | 3 | | | | | 56 |
| Eskdalemuir | | | | | | 15 | 9 | | | | | | 24 |
| Douglas | | | | 9 | 31 | 34 | | 6 | | | | | 80 |
| Cockle Park | | | | 3 | 28 | 28 | | 6 | | | | | 65 |
| Tynemouth | | | | 3 | 34 | 37 | | 12 | | | | | 86 |
| Durham | | | | 15 | 53 | 43 | | 9 | | | | | 120 |
| York | | | | 39 | 96 | 81 | | 24 | | | | | 240 |
| Spurn Head | | | | 15 | 59 | 65 | | 36 | | | | | 175 |
| Gorleston | | | | 15 | 68 | 84 | | 45 | | | | | 212 |
| Felixstowe | | | | 40 | 105 | 112 | | 66 | | 3 | | | 326 |
| Cambridge | | | | 3 | 42 | 112 | | 102 | | 45 | | | 304 |
| Rothamsted | | | | 21 | 87 | 47 | | 36 | | | | | 191 |
| Sheffield | | | | 39 | 93 | 77 | | 25 | | | | | 234 |
| Nottingham | | | | 3 | 45 | 109 | | 93 | | 33 | | | 283 |
| Birmingham | | | | | | | | | | | | | |
| (Sparkhill) | | | | 3 | 42 | 112 | | 90 | | 30 | | | 277 |
| Oxford | | | | 3 | 45 | 124 | | 105 | | 42 | | | 319 |
| Ross-on-Wye | | | | | 36 | 102 | | 81 | | 24 | | | 243 |
| Kew | | | | 6 | 63 | 146 | | 124 | | 54 | | | 393 |
| Wisley | | | | 3 | 45 | 121 | | 115 | | 51 | | | 335 |
| Dungeness | | | | | 15 | 71 | | 87 | | 57 | | 3 | 233 |
| Southampton | | | | 3 | 54 | 121 | | 121 | | 51 | | 6 | 356 |
| Ventnor | | | | | 39 | 109 | | 121 | | 69 | | 9 | 347 |
| Marlborough | | | | | 18 | 71 | | 59 | | 21 | | | 169 |
| Porton | | | | | 27 | 84 | | 74 | | 30 | | | 215 |
| Keswick | | | | | 27 | 50 | | 43 | | 9 | | | 129 |
| Manchester | | | | | | | | | | | | | |
| (Whitworth | | | | | | | | | | | | | |
| Park) | | | | | 48 | 99 | | 93 | | 33 | | | 273 |
| Southport | | | | | 21 | 68 | | 59 | | 15 | | | 163 |
| Stonyhurst | | | | | 24 | 59 | | 50 | | 9 | | | 142 |
| Bidston | | | | | 21 | 68 | | 62 | | 15 | | | 166 |
| Holyhead | | | | | 3 | 37 | | 50 | | 18 | | | 108 |
| Welshpool | | | | | 27 | 71 | | 68 | | 15 | | | 181 |
| St. Ann's Head | | | | | 9 | 47 | | 50 | | 21 | | | 127 |
| Cardiff | | | | | 45 | 93 | | 90 | | 33 | | | 261 |
| Portland Bill | | | | | 15 | 56 | | 77 | | 42 | | 6 | 199 |
| Shaftesbury | | | | | 24 | 84 | | 65 | | 33 | | | 206 |
| Cullompton | | | | | 51 | 105 | | 93 | | 30 | | | 279 |
| Plymouth | | | | | | | | | | | | | |
| (Mountbatten) | | | | | 45 | 93 | | 96 | | 51 | | 3 | 288 |
| Scilly | | | | | 18 | 68 | | 84 | | 75 | | 3 | 248 |
| Armagh | | | | | 18 | 43 | | 37 | | 6 | | | 104 |

Where no figure is given, the average is zero

for each month at a place whose altitude is h feet. Thom's expression for the monthly degree-day average is

$$\bar{D} = N(60 - \bar{t} + l\sqrt{N}\sigma_m).$$

By using published maps of average daily mean temperature,^{7,8} monthly values of $(\bar{t} + h/300)^\circ\text{F.}$ can be obtained. Hence values of $\bar{t}^\circ\text{F.}$ can be calculated by subtracting the altitude correction $h/300$. Similarly monthly values of σ_m

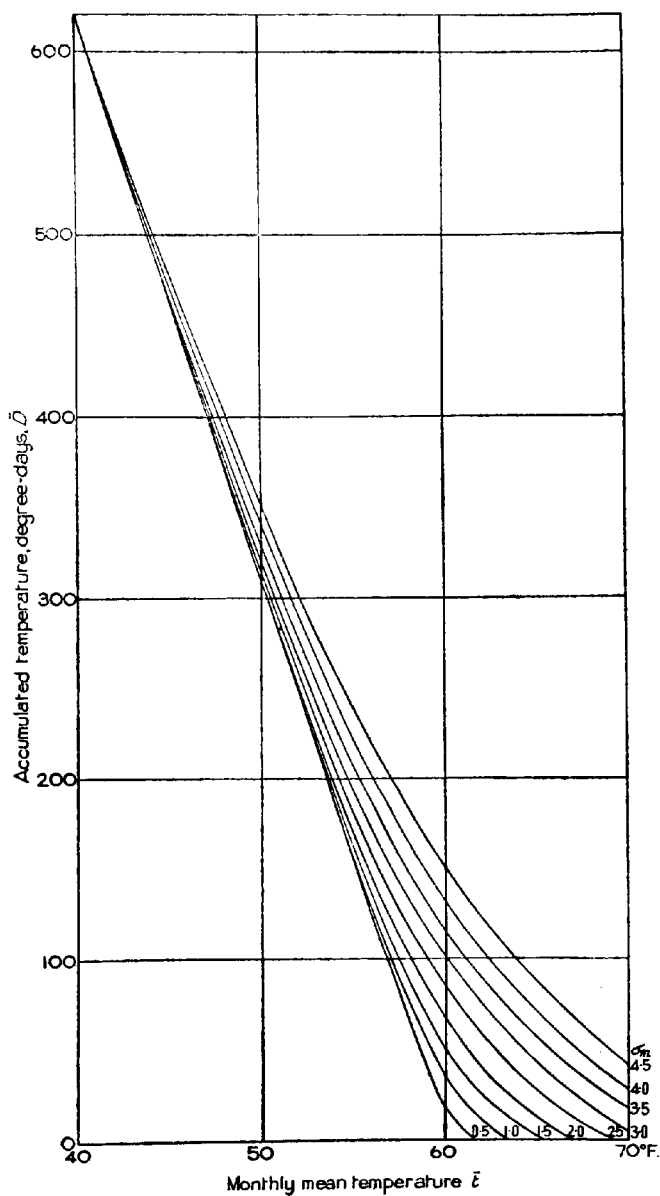


FIGURE 3—RELATION BETWEEN ACCUMULATED TEMPERATURE BELOW 60°F. AND MONTHLY MEAN TEMPERATURE FOR VARIOUS VALUES OF σ_m AND $N = 31$

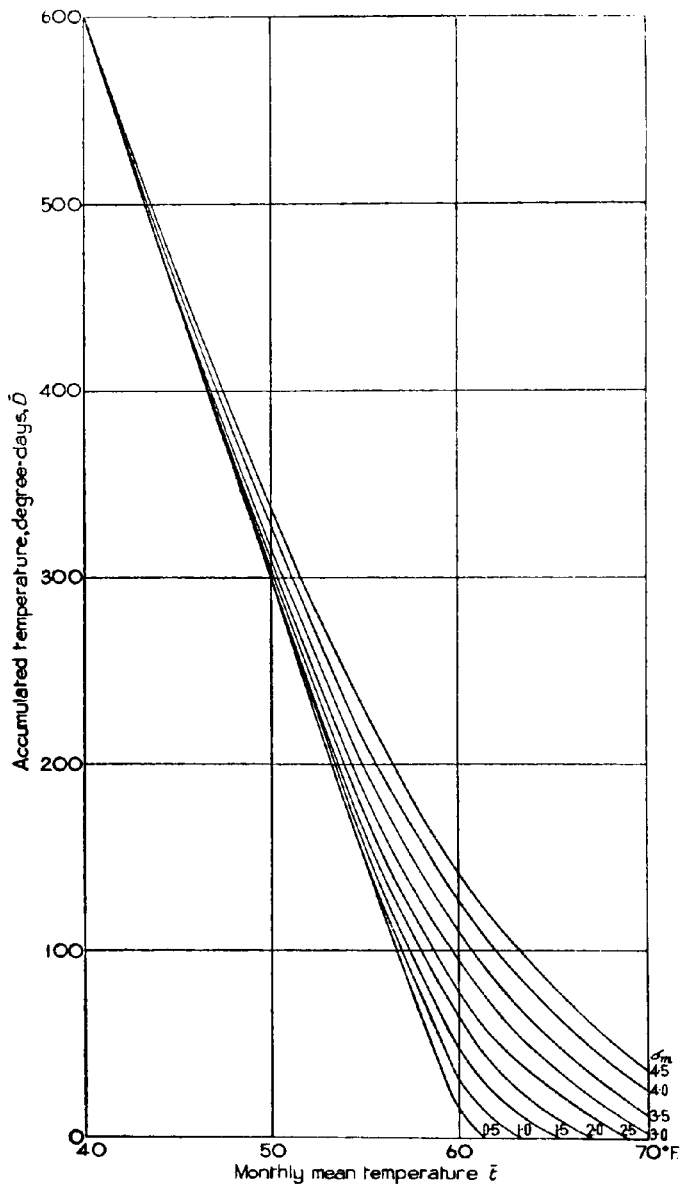


FIGURE 4—RELATION BETWEEN ACCUMULATED TEMPERATURE BELOW 60°F. AND MONTHLY MEAN TEMPERATURE FOR VARIOUS VALUES OF σ_m AND $N = 30$

can be read off from the maps given in Part II. Curves have been drawn relating \bar{D} with \bar{i} for various values of σ_m and for $N = 31$ and are reproduced in Figure 3. Similar curves for $N = 30$ are given in Figure 4. Thus, if in July $\bar{i} = 57.5$ and $\sigma_m = 2.2$ it can be seen from Figure 3 that \bar{D} , the average accumulated temperature below 60°F ., is about 118 degree-days. Similarly the values for the other 31-day months can be obtained from Figure 3 and those for 30-day months from Figure 4. In the case of February and all other months with \bar{i} less than 40°F . the required value is simply $N(60 - \bar{i})$. The monthly estimates can then be summed to give the required seasonal or annual values.

Example.—Estimate the average annual accumulated temperature below 60°F . at Askrigg, Yorks, altitude 750 feet. The altitude correction for temperature is $750/300 = 2.5^\circ\text{F}$. Using maps of average temperature⁸ and those in Part II of this Note, respectively, the following monthly values of \bar{i} (map value -2.5°F .) and σ_m are obtained. The corresponding values of \bar{D} are thence obtained by the method just described. They are equal to $N(60 - \bar{i})$ for the months December to March, and are read off from Figures 3 or 4, as appropriate, for the remaining months.

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|------------|------|------|-------|-------|------|------|------|------|-------|------|------|------|
| \bar{i} | 36.0 | 36.4 | 39.5 | 43.6 | 49.6 | 53.4 | 58.3 | 57.0 | 52.9 | 46.4 | 40.3 | 37.3 |
| σ_m | 3.7 | 3.5 | 3.0 | 2.4 | 1.9 | 2.1 | 1.9 | 2.0 | 2.1 | 2.1 | 2.3 | 3.1 |
| \bar{D} | 744 | 667 | 635 | 492 | 322 | 208 | 94 | 123 | 221 | 422 | 591 | 704 |

The sum of the twelve monthly values of \bar{D} is 5,223 degree-days, which is the average value required. It is of interest to note that interpolation from Figure 1 would have given a value of something over 5,000, while Figure 2 would give a mean-sea-level value of about 4,450 and, assuming an altitude correction of 1.1 degree-days per foot, this would give a station level average of $4,450 + 825 = 5,275$ degree-days.

Probable effects of local climate variations.—Mention has already been made of urban effects. These may raise the average temperature of a city by 1 or 2°F . above that of the surrounding area. This corresponds to a decrease of from 300 to 600, or of some 7 to 15 per cent, in the average number of degree-days per annum below 60°F . The effect of altitude has been taken into account, but only as far as temperature is concerned. Higher sites will in general also have higher wind speeds and this will mean that average fuel requirements may be higher than is indicated by the average accumulated temperature. The effects of local temperature variations between sites having different aspects and exposures are not likely to be very large. For example, although an enclosed valley will have appreciably lower night minimum temperatures than a hill-top nearby, it will also have appreciably higher day maxima and the mean temperatures of the two sites will tend to be much the same. Similarly, the main effects of woods or of adjacent deep water are to decrease the diurnal range of temperature leaving the mean values little changed.

PART II

MAPS OF STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE, 1921-50

Introduction.—It is customary to assess the character of the weather during a month by the departures from the long-period averages of the main elements. Departures from average of the monthly mean temperature, usually derived from $\frac{1}{2}(\text{mean daily maximum} + \text{mean daily minimum})$, are published in the *Monthly Weather Report* and also in the *Monthly Summary of the Daily Weather Report*. If for any particular station the monthly mean temperature and its departure from the long-period average are given it is not always easy to assess the extent to which the month has been unusual in respect of temperature. To do this with any precision it is useful to know the frequency with which any given departure from average is likely to occur and for this an estimate of the variance of the monthly means about the long-period average is required.

If the standard deviation of the mean temperatures for any month is σ , then assuming a normal distribution it can be said, for example, that more than 95 per cent of the months of that name will have mean temperatures which lie between -2σ and $+2\sigma$ on each side of the average. Thus, if σ for January is 3.0°F. at a station, then the probability of a single January being 6.0°F. or more colder than the average is less than $2\frac{1}{2}$ per cent, that is, on the average a January as cold as this would occur only once in about 43 years. At another station where the January standard deviation is 4.0°F. , the same departure from average would be equalled or exceeded on the average once in about 15 years and would be correspondingly less noteworthy.

Thus a knowledge of the distribution of the standard deviation of monthly mean temperature over the country is of importance in judging the significance of any given departure from average especially if, as will be shown, it varies quite appreciably from one place to another and in different months of the year.

Values of the standard deviations for each month have been computed for 52 stations with records covering the standard period 1921-50, thus providing a reasonably good network over Great Britain and Northern Ireland. These values may be used in conjunction with the published temperature averages for the same period.⁶ They are presented in the form of maps on which the individual station values are plotted and on which isopleths at intervals of $\frac{1}{2}^{\circ}\text{F.}$ have been drawn in.

Stations used.—The 52 stations used included all those mentioned in Table III except that Plymouth (Mountbatten) was replaced by Plymouth (The Hoe), $50^{\circ}22'\text{N.}$, $4^{\circ}8'\text{W.}$, 117 feet. The remaining three stations, all in Eire, were included to assist in drawing the isopleths over Northern Ireland. They were : Dublin (Glasnevin), $53^{\circ}23'\text{N.}$, $6^{\circ}16'\text{W.}$, 55 feet ; Malin Head, $55^{\circ}23'\text{N.}$, $7^{\circ}24'\text{W.}$, 84 feet ; Markree Castle, $54^{\circ}11'\text{N.}$, $8^{\circ}27'\text{W.}$, 122 feet. The period of years for Tírree was 1927-50.

Discussion.—It will be seen from the maps that in all months the standard deviations are smaller on the coasts than they are inland, showing the effect of the sea in reducing the climatic variability. There is also an appreciable variation during the year, values being about twice as great in winter as they are in summer. Over the 30-year period considered January and February are, on the whole, the most variable months, standard deviations being highest in January over Scotland and Northern Ireland and in February over England and Wales. The high February values may be partly due to the inclusion in the period of the outstandingly cold February of 1947 and partly because of the

shorter month. The month showing least variability in most places is May, but June has the lowest values over parts of the Midlands and south-east England and July in a coastal strip from Aberdeen to Felixstowe. There is evidence of a marked change in the distribution between February and March, a shifting northwards of the region of maximum variability, so that over Scotland March is not very different from February. In order to bring out the differences between Scotland, England and Wales and Northern Ireland, Table X has been compiled. This gives estimates of the average variability, expressed as a standard deviation, in each month over each of the three countries. They were obtained by reading off values from the maps at points on a suitable grid (20 points over England and Wales, 10 over Scotland and 3 over Northern Ireland), squaring them to obtain the variances and taking the square root of the average variance over each country.

TABLE X—GENERAL VALUES OF STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.)

| | Jan. | Feb. | March | April | May | June | July | Aug. | Sept. | Oct. | Nov. | Dec. |
|-------------------|------|------|-------|-------|-----|------|------|------|-------|------|------|------|
| England and Wales | 3.3 | 3.5 | 2.5 | 2.2 | 1.6 | 1.8 | 1.9 | 1.9 | 2.1 | 1.9 | 2.2 | 2.9 |
| Scotland | 3.0 | 2.9 | 2.9 | 2.1 | 1.5 | 1.9 | 1.6 | 1.7 | 1.9 | 1.8 | 2.0 | 2.7 |
| Northern Ireland | 2.7 | 2.6 | 2.4 | 2.3 | 1.3 | 1.7 | 1.6 | 1.7 | 1.7 | 1.6 | 1.9 | 2.5 |

The table confirms that May is in general the least variable month as regards temperature, although over Scotland July runs it fairly close. February is the most variable month in England and Wales, but in the other two countries January leads, although in Scotland February and March are not far behind.

The main use which can be made of these standard deviations has been mentioned in the introduction. Table XI, based on the normal distribution, gives the probabilities, corresponding to various values of the standard deviation, that any particular departure from average will be equalled or exceeded. They are expressed as the number of occasions in 100 years.

TABLE XI—PROBABILITY THAT GIVEN DEPARTURES FROM AVERAGE WILL BE EQUALLED OR EXCEEDED : NUMBER OF OCCASIONS IN 100 YEARS

| Departure from average (°F.), plus or minus | Standard deviation (°F.) | | | | | | | | | |
|--|---|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| | 0.5 | 1.0 | 1.5 | 2.0 | 2.5 | 3.0 | 3.5 | 4.0 | 4.5 | 5.0 |
| | <i>number of occasions in 100 years</i> | | | | | | | | | |
| 1.0 | 2.3 | 16 | 25 | 31 | 34 | 37 | 38 | 40 | 41 | 42 |
| 2.0 | 0.0 | 2.3 | 9 | 16 | 21 | 25 | 28 | 31 | 33 | 34 |
| 3.0 | 0.0 | 0.1 | 2.3 | 7 | 11 | 16 | 19 | 22 | 25 | 27 |
| 4.0 | | 0.0 | 0.4 | 2.3 | 5 | 9 | 13 | 16 | 19 | 21 |
| 5.0 | | | 0.0 | 0.6 | 2.3 | 4.8 | 8 | 10 | 13 | 16 |
| 6.0 | | | | 0.0 | 0.1 | 0.8 | 2.3 | 4.3 | 7 | 9 |
| 7.0 | | | | | 0.0 | 0.3 | 1.0 | 2.3 | 4.0 | 6 |
| 8.0 | | | | | 0.0 | 0.1 | 0.4 | 1.1 | 2.3 | 3.8 |
| 9.0 | | | | | | 0.0 | 0.1 | 0.5 | 1.2 | 2.3 |
| 10.0 | | | | | | | 0.0 | 0.2 | 0.6 | 1.3 |
| 11.0 | | | | | | | | 0.0 | 0.1 | 0.3 |
| 12.0 | | | | | | | | | 0.0 | 0.1 |

Suppose, for example, that it is required to know the chance in January of a mean temperature which is 4.0°F. or more below the average at Oxford. The standard deviation is seen from the January map to be 3.8°F. and looking along

the row for 4.0°F. it is seen that such a departure will be equalled or exceeded about 15 times in 100 years. At Wick, where the January standard deviation is only 2.1°F., the same departure can be expected to be equalled or exceeded only two or three times in 100 years. The mean monthly temperature at Oxford in August, 1947, was 4.8°F. above average. The August standard deviation is 2.1°F. and the table shows that the chance of such a hot August is only about one in one hundred.

The maps can also be used, as already described in Part I, in connexion with the calculation of approximate averages of accumulated temperature above or below any desired base temperature by a statistical method due to Thom.⁵

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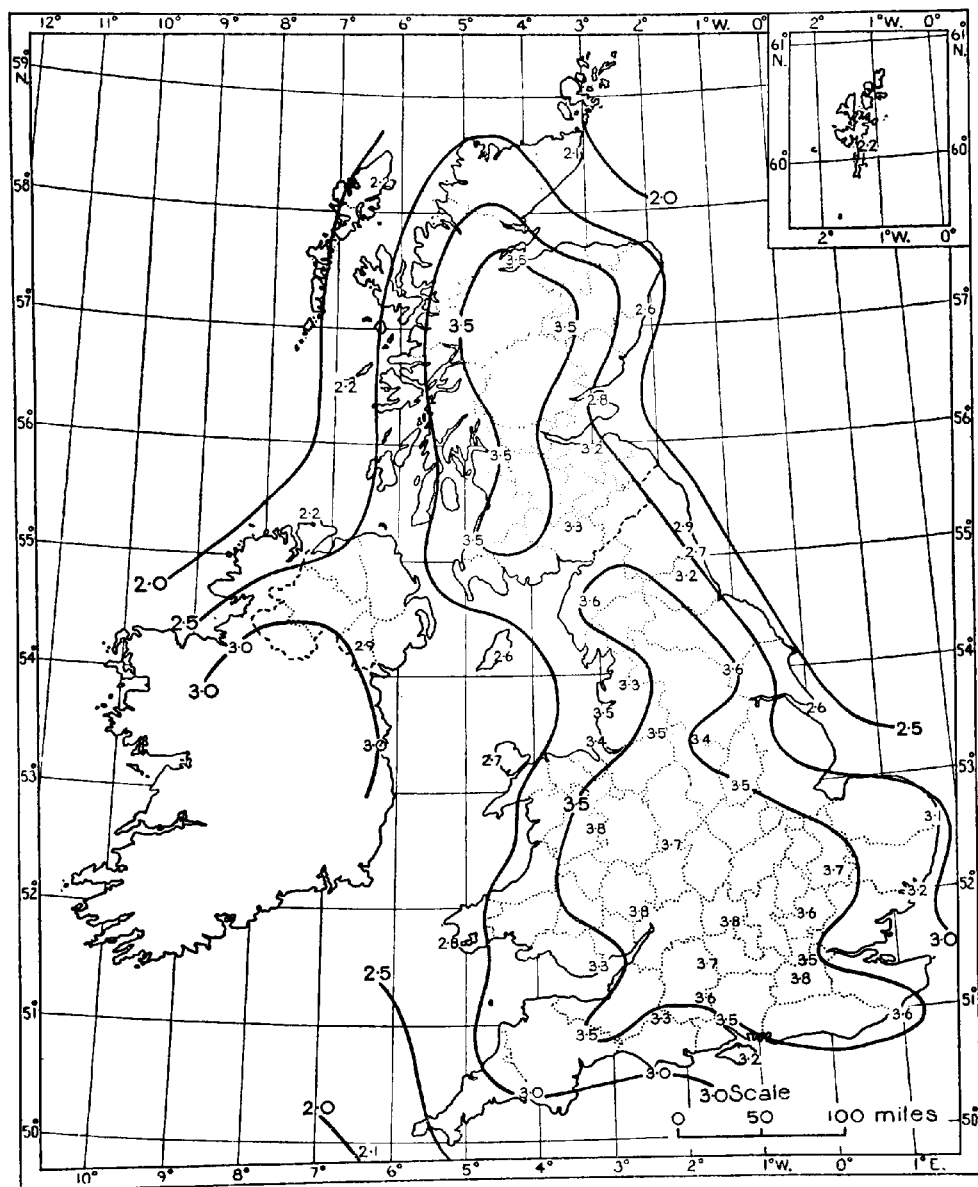


FIGURE 5—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, JANUARY

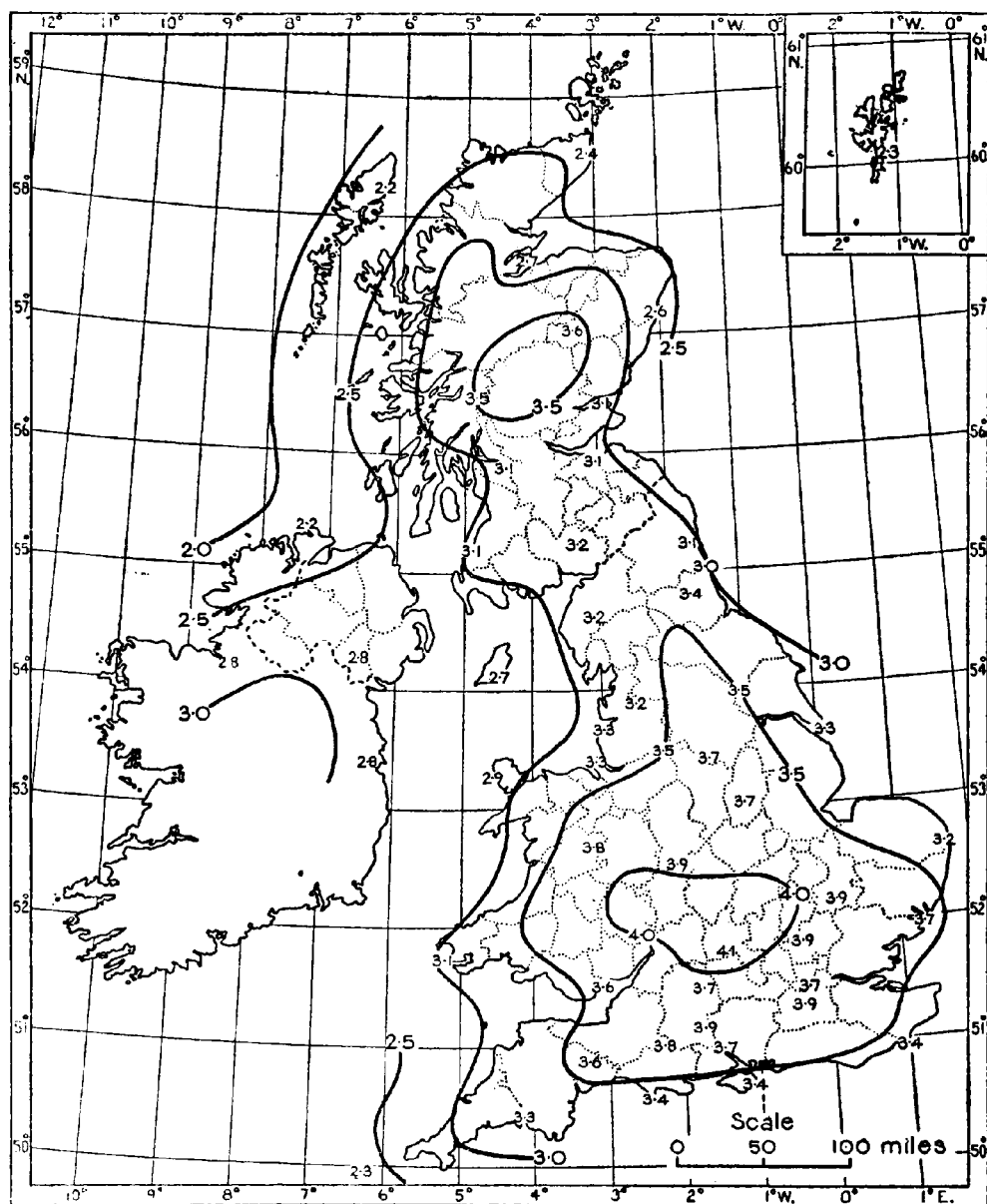


FIGURE 6—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, FEBRUARY

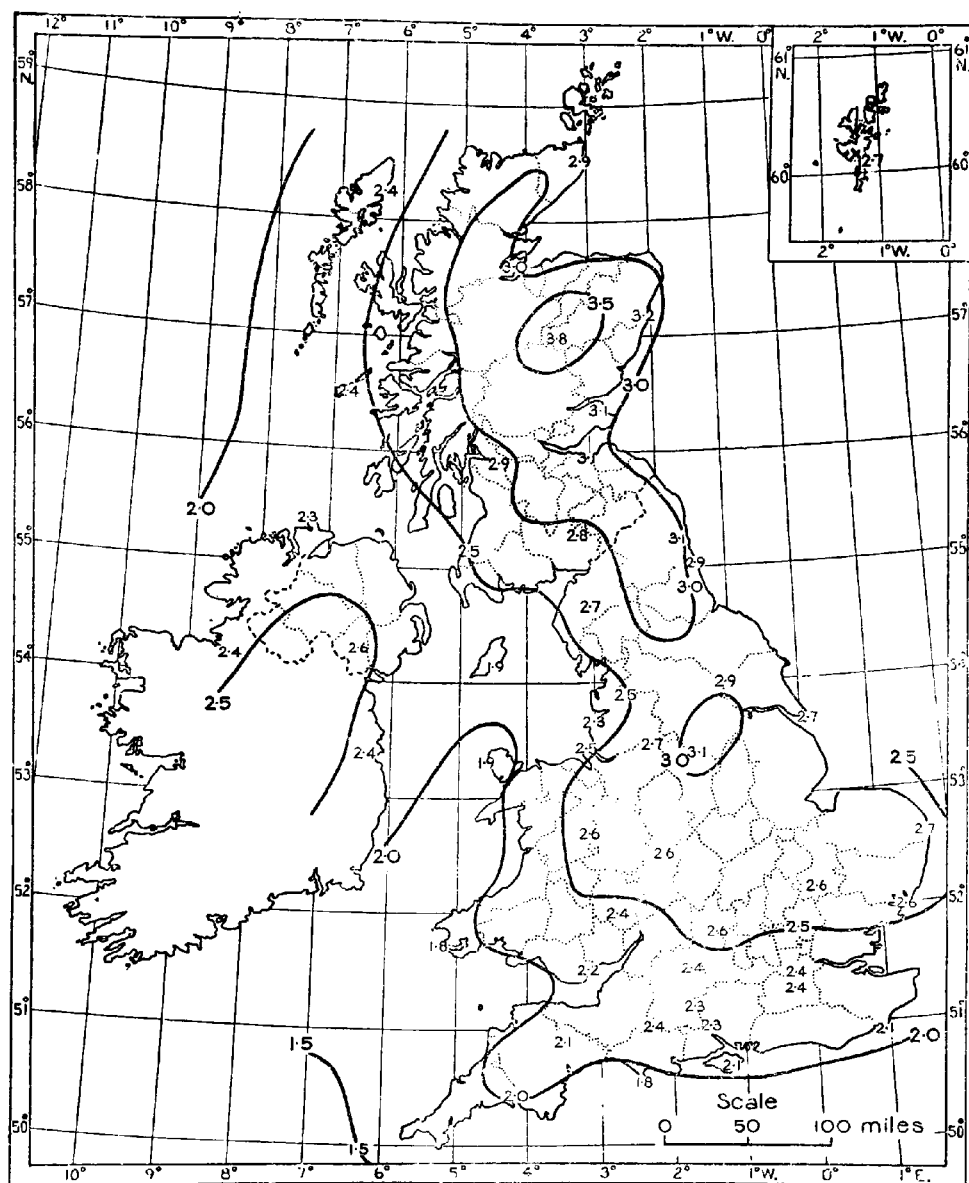


FIGURE 7—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, MARCH

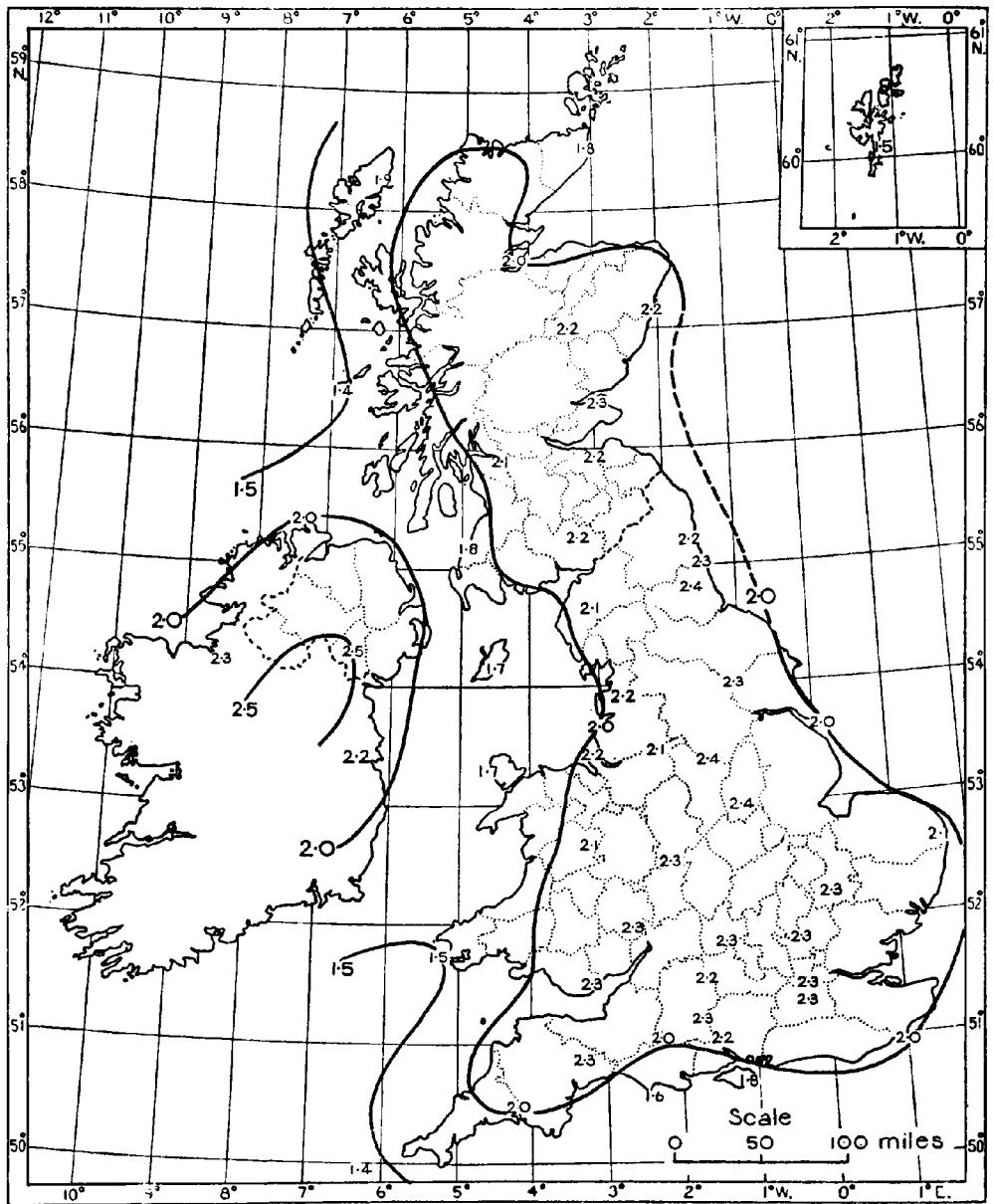


FIGURE 8—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, APRIL



FIGURE 9—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50,
MAY

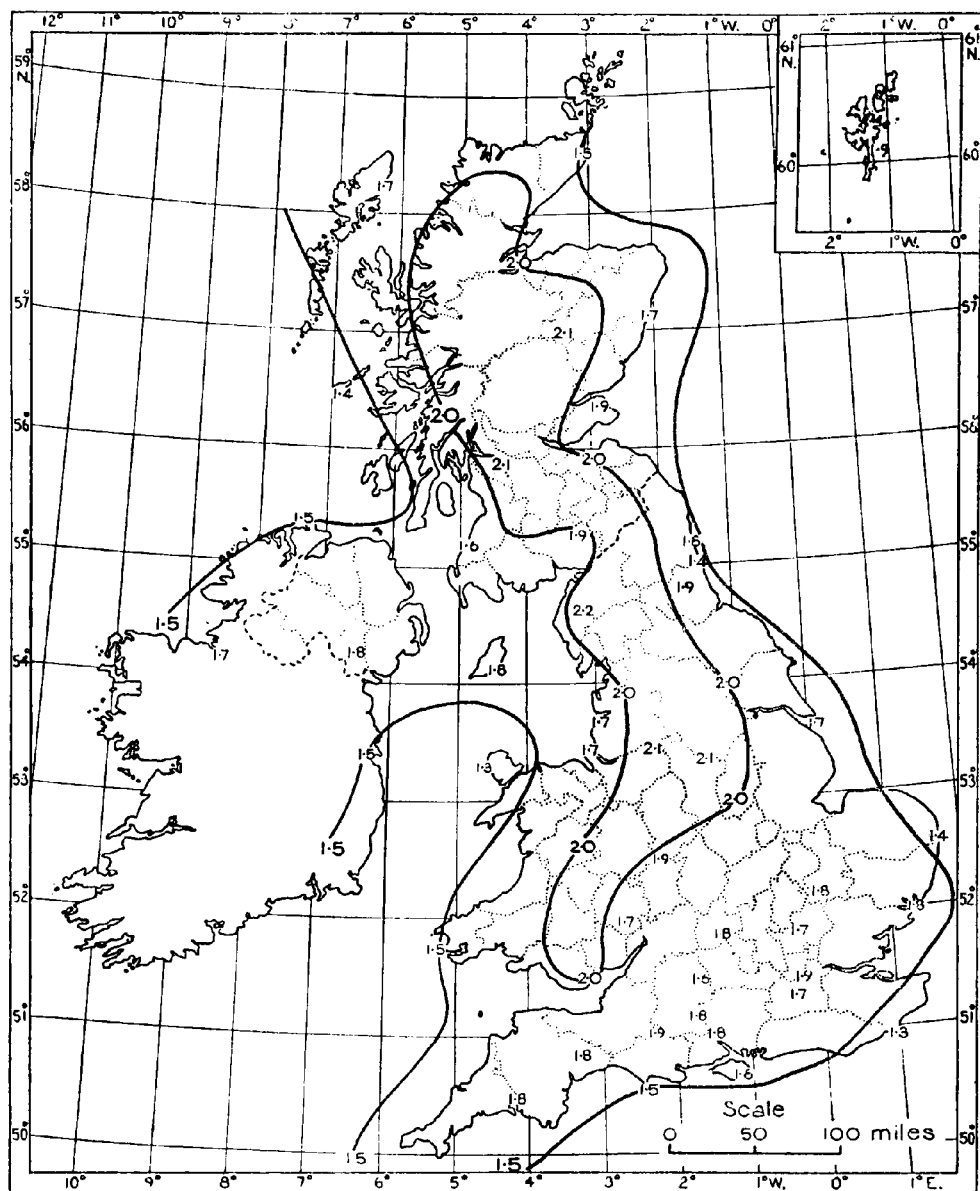


FIGURE 10—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, JUNE

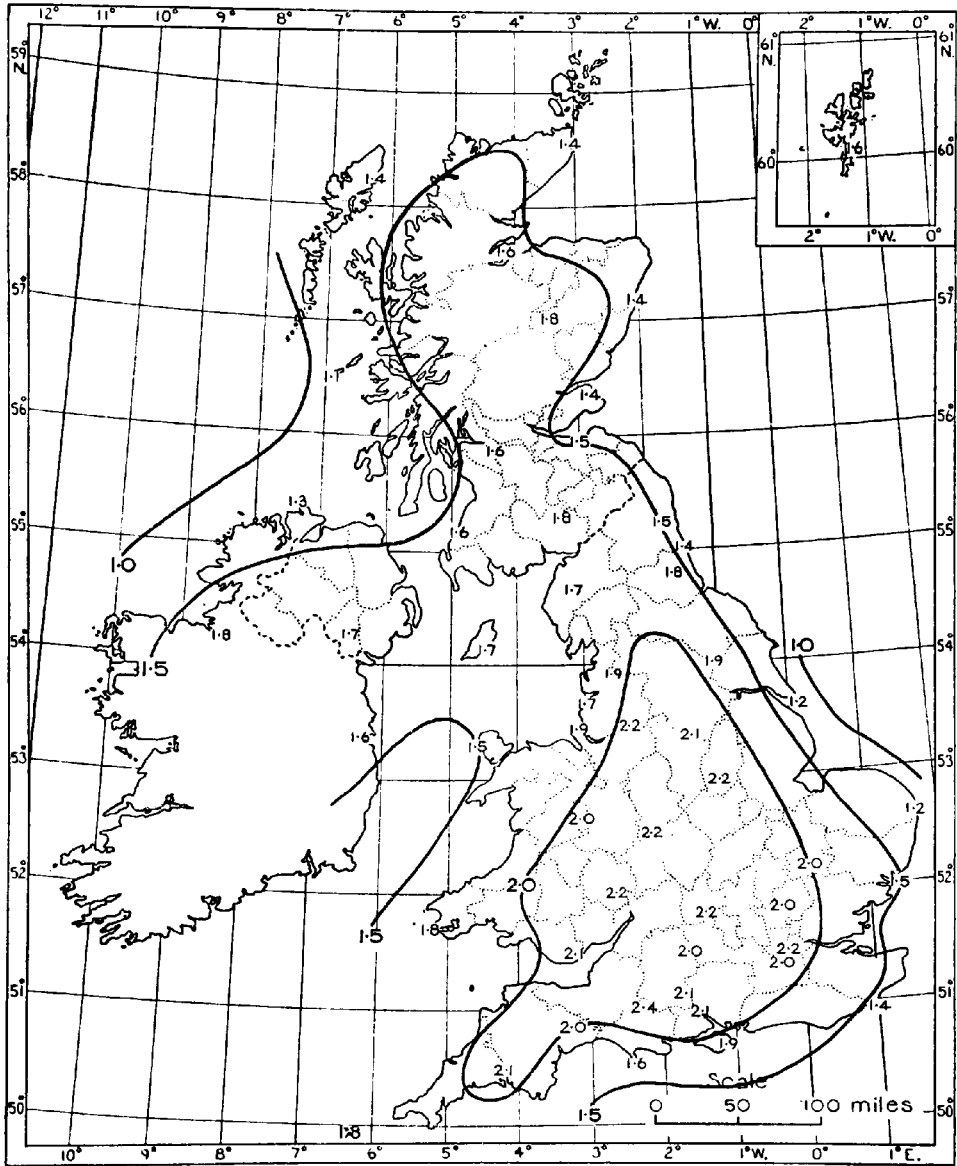


FIGURE 11—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, JULY

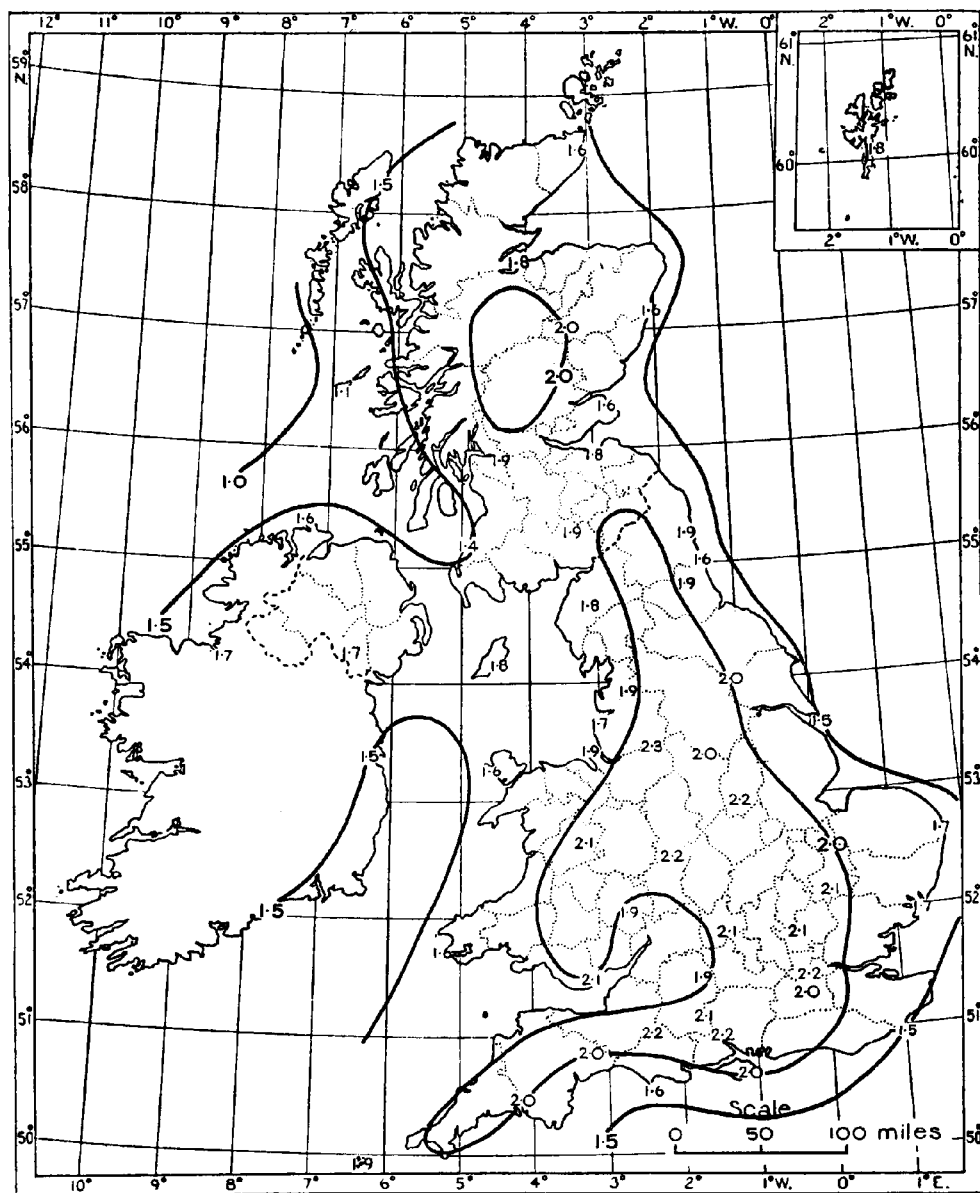


FIGURE 12—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, AUGUST

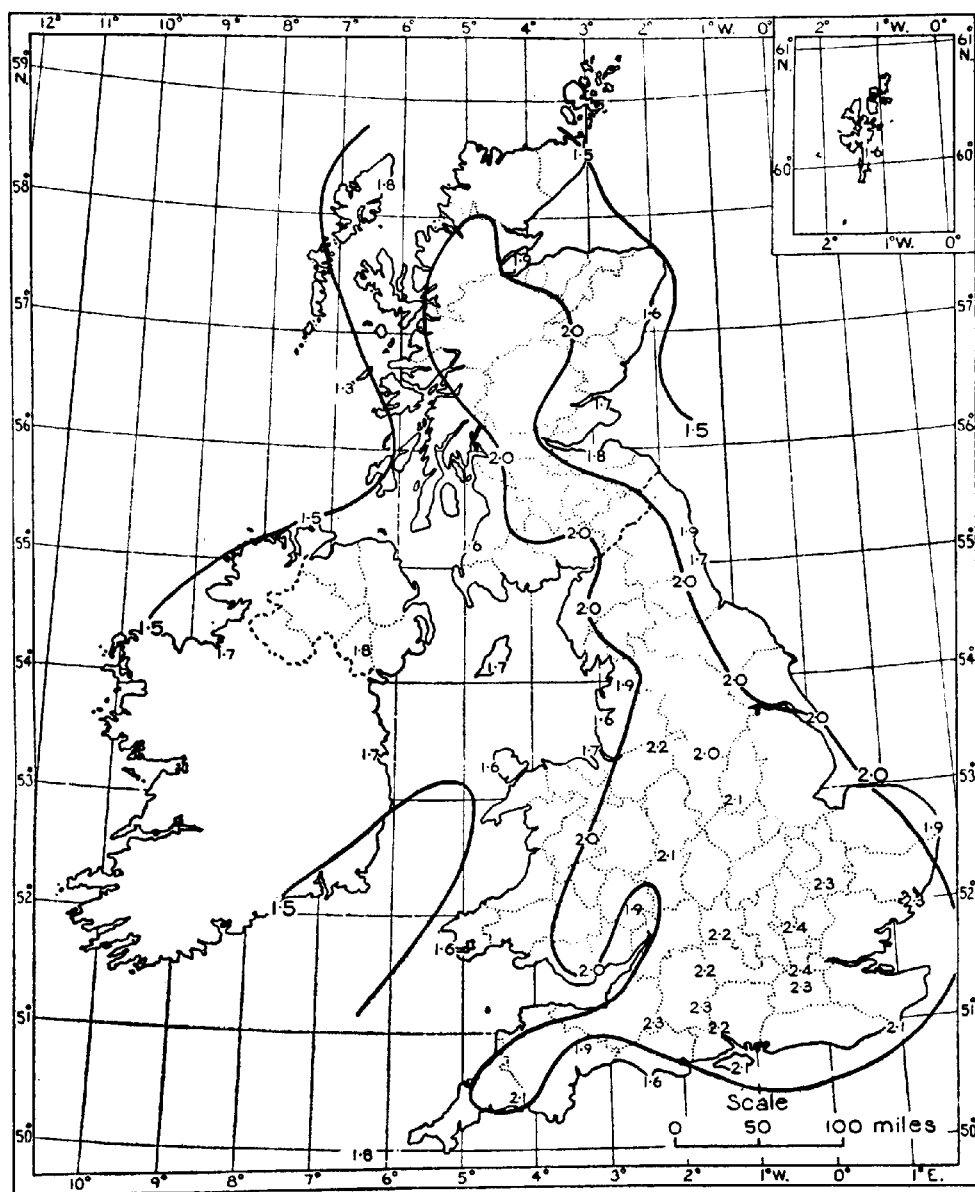


FIGURE 13—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50.
SEPTEMBER

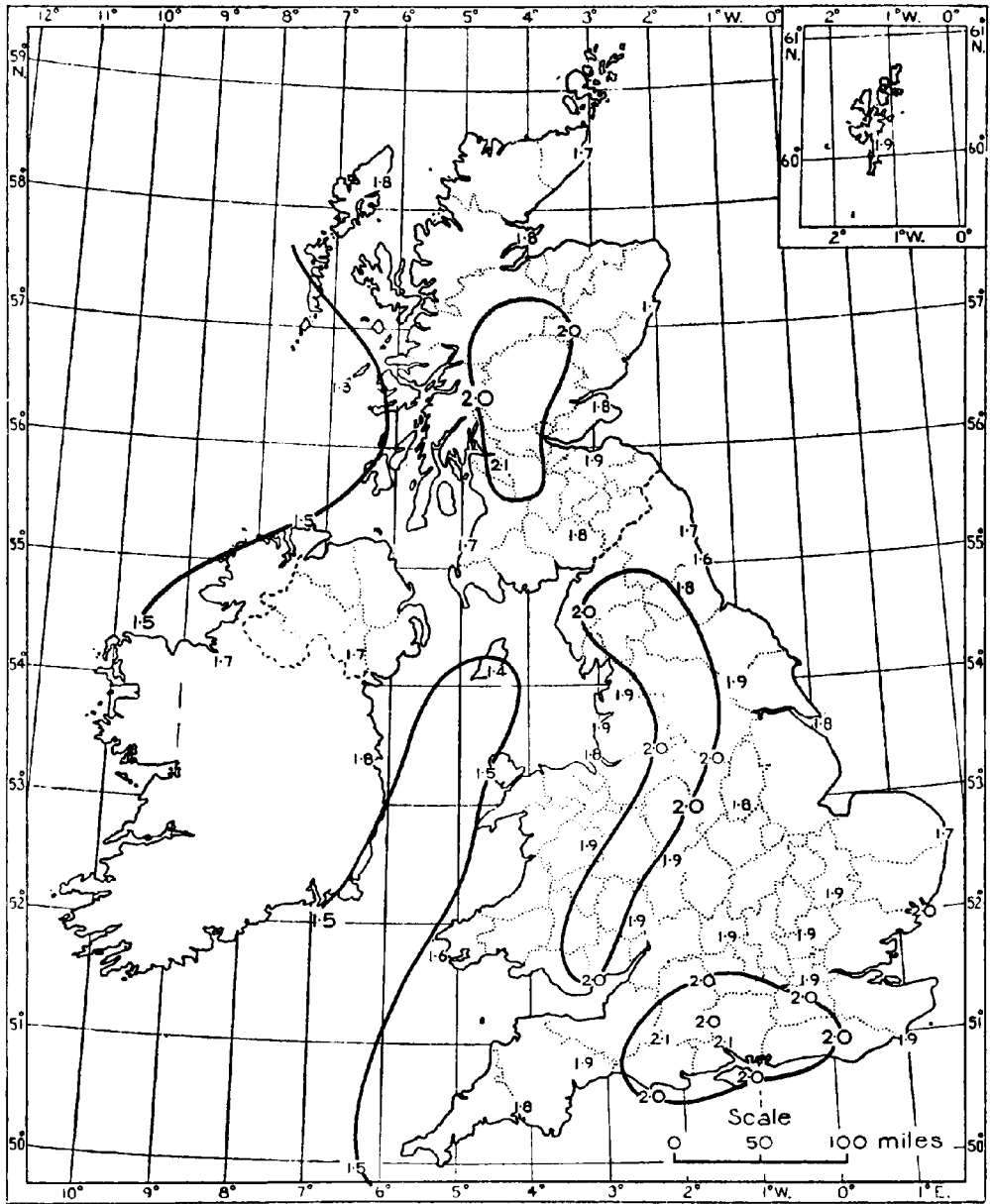


FIGURE 14—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, OCTOBER

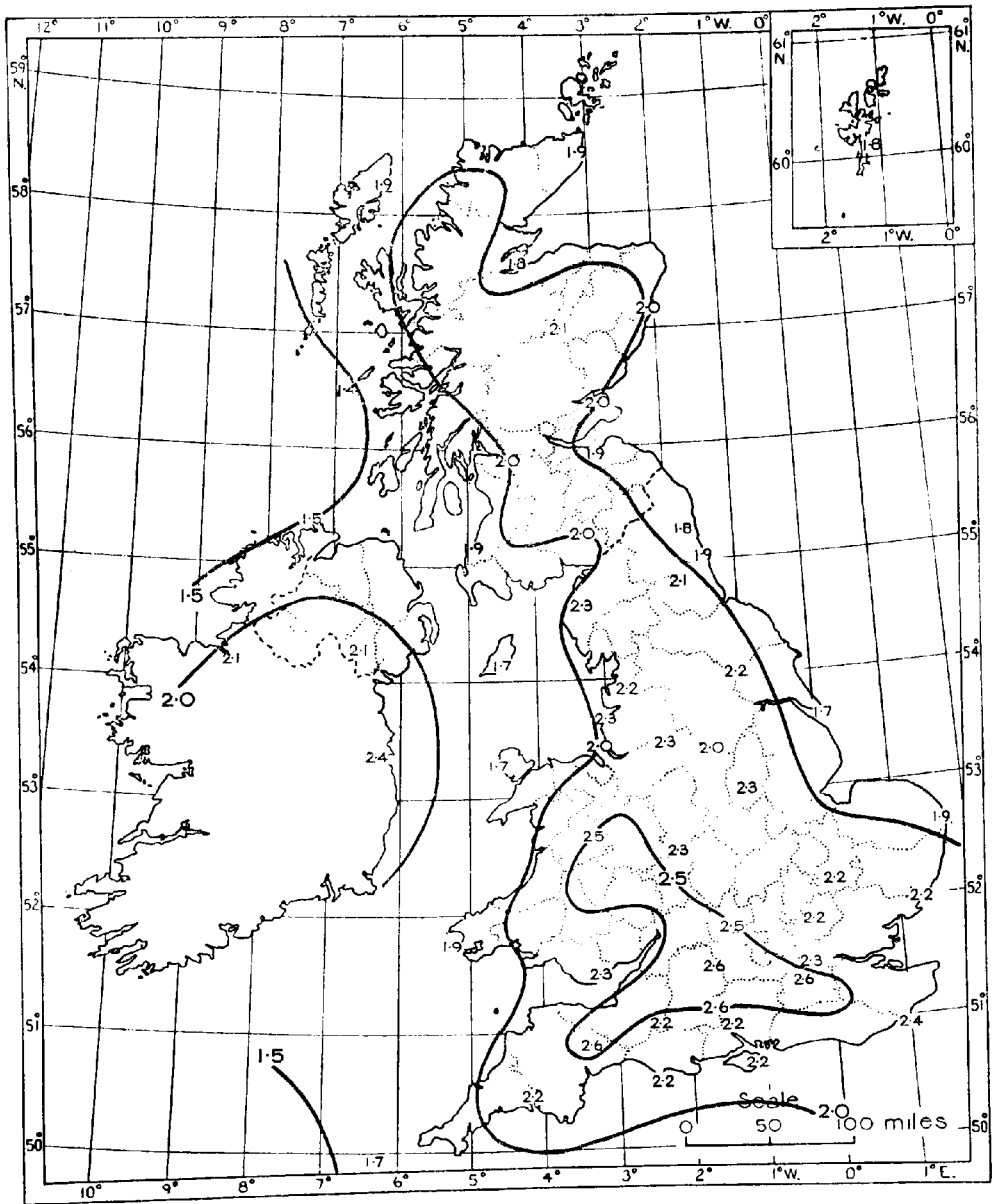


FIGURE 15—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, NOVEMBER

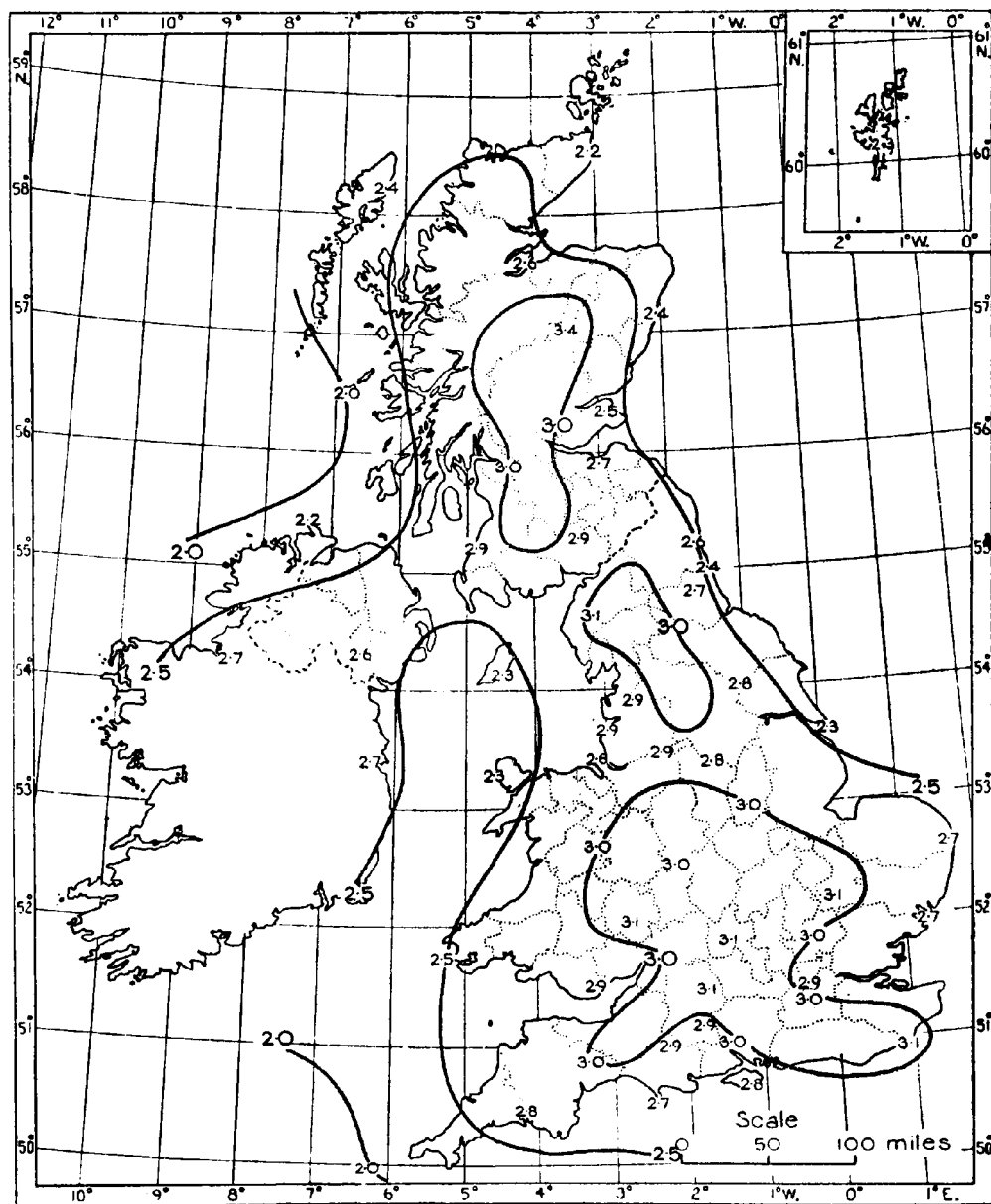


FIGURE 16—STANDARD DEVIATION OF MONTHLY MEAN TEMPERATURE (°F.), 1921-50, DECEMBER

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