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METEOROLOGICAL OFFICE

Scientific Paper No. 12

Some statistical relationships between the temperature anomalies in neighbouring months in Europe and western Siberia

by J. M. CRADDOCK, M.A.
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Contents

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SUMMARY

Relationships are sought between the temperature anomaly in any given month and that in each of the preceding 21 months at any of 15 climatological stations in northern and central Europe. In some geographical areas and in some months of the year there is a strong tendency for the temperature anomaly to persist from one month to the next while in other areas and seasons there is little association between the temperature anomalies in consecutive months. There are a few areas in which, in particular months, the temperature anomaly is associated with that which occurred two or three months earlier. The areas of association are determined with as much detail as possible, using a simplified method of analysis, and data for an open network of about 100 stations.

INTRODUCTION

This research was planned without any expectation of startling results, with a view to clearing the ground and outlining the field within which more elaborate methods of investigation can be used with the best prospects of success. The popular saying that a warm summer follows a hard winter is the sort of statement which is easy to make but hard to justify, since no one in his lifetime can observe enough cases to settle the question. In this paper we make a systematic search for such simple relationships using the longest available climatic records. We examine by means of contingency tables the relation between the temperature anomalies in one particular calendar month and those in each of several earlier months and use the chi-squared test to decide which relationships are unlikely to arise by chance. The investigation is repeated for each month of the year.

METHOD

For each station for each year we get a pair of variables (say the mean temperature anomalies in April and June) and our problem is to decide whether, considering all years for which records are available, or any selection of them, there is evidence of association between the variables. Where the relation between the variables is known or assumed to be linear, the correlation coefficient provides a satisfactory measure of their association. In the present work, however, we wish to detect any non-linear relationships which may exist and also to provide, for example, for the possibility that in one particular month an above normal temperature bears a definite relation to the temperatures in future months while a normal or below normal temperature has no prognostic value. We therefore decided to examine the relationships by means of contingency tables, using the chi-squared test to single out the potentially significant tables which are unlikely to arise by chance if the variables in question are in fact independent.

This choice of method restricts our choice and treatment of data to the extent necessary to ensure that the chi-squared test should give reliable indications. If the chi-squared test is to work properly, the first requirement is that the expected number in any category should not be too small. If we insist on a minimum of five cases in each category, then we need at least $5 \times 3 \times 3 = 45$ years' data for a 3×3 table. Since in practice we cannot ensure that exactly equal numbers of cases fall in each category, we used 60–80 years' data whenever possible. Corresponding requirements for a 5×5 table are 125 years' data as the absolute minimum and 150–200 years' in practice. Therefore we used 5×5 tables for all stations having long enough observational records.

The second requirement for the validity of the chi-squared test is that each pair of observations used should be statistically independent of any other. If they are not, then spuriously large values of chi-squared can arise by chance.

Our problem is to find a method of sorting say the January mean temperatures observed during a period of 60–200 years into three or five categories, according to magnitude so that

(i) about equal numbers go into each category, and

(ii) the cases after classification appear in approximately random order, so that there is no tendency, for example, for the very cold cases to be grouped together in one part of the series.

We decided to sort the temperatures into groups whose limits were the terciles or quintiles of a Gaussian distribution having its mean and standard deviation agreeing with the data, but then had to consider how these statistics should be calculated. We intended originally to use a standard period of years (for example, 1901–1940) but it appeared that when we were considering from 150–200 years' data, then for some stations the statistics for 1901–1940 were not even approximately representative of the whole. Further preliminary work went to show that if the sorting was carried out according to any reasonable standard which was maintained unchanged during the whole period, then the cases after sorting would not be in random order, but would have the warm and the cold months tending to occur in groups. Coherence of this kind is most undesirable since it invalidates the statistical treatment and greatly increases the difficulty of reaching firm conclusions. We decided that we must measure the anomalies from a moving standard which would eliminate the effect of climatic and any other slow interannual changes while not affecting much the relationships between any one year and its neighbours. The total period of years' data for each station was divided into sections of 8 years, and the anomalies for each month within any section were based on statistics calculated for that section. The choice of 8 years as opposed to, say, 5, 10 or 15 was a matter of convenience in the electronic computation, the basic requirement being for a period so short that any climatic change within it will be negligible. However, a mean over a very short period is liable to be unduly affected by the variations from one year to the next, so the 8-year means for the 12 calendar months were smoothed by the process of harmonic analysis described by Craddock*. The harmonic estimates should be and are smoother than the 8-year monthly means, while still responding to any continued climatic change. Estimates of monthly variances based on only 8 observations would have been very unstable, so for this element the estimates were pooled for all the 8-year periods. The anomalies were then measured from the mean for the appropriate 8-year period and were classed according to the standard deviations for the whole period. The resulting series of anomalies for a given month then appeared to be in random order, as required for the validity of the statistical treatment.

*CRADDOCK, J. M.; The variation of the normal air temperature over the Northern Hemisphere during the year. *Met. Res. Pap., London*, No. 917, 1955. (Unpublished; copy available in Meteorological Office Library.)

This question of deciding on the standards from which the anomalies are to be measured is the most controversial aspect of the whole paper. We would have preferred a more natural method of estimation than the one used, but the question of how to arrive at the best method is big enough for a separate investigation. Later work not yet completed using several alternative methods of estimation goes to suggest that our present method has produced most of the important results and led to nothing misleading, but that more elaborate methods may at the cost of considerable extra effort extract a little more from the data.

DATA AND COMPUTATION

Particulars of the data used are given in Table I. The stations with records long enough to enable 5×5 tables to be used are in italics. These as well as the rest were also analysed with 3×3 tables.

Each relationship is specified by the number (1–12) of the later of the two months concerned and by the lag which is the difference in months between the two. Thus the computation for "February lag 1" will examine the associations between anomalies in January and February. In order to determine the largest lag for which significant relations may be found, we carried out an analysis with 5×5 contingency tables on all the stations for which the observational records were long enough, for every month of the year for all lags from 1–21. It was then apparent that for large lags the high values of chi-squared did not exceed, in number or magnitude, the chance expectation and that the population of values of chi-squared was sufficiently close to expectation to rule out the risk of serious errors in the statistical treatment.

TABLE I. *Stations for which month-to-month temperature relationships have been investigated. All stations were examined by using* 3×3 *contingency tables—for those in italics* 5×5 *contingency tables were used as well*

Station	Period	No. of Years	Lat.	Long.	Height in metres
Aberdeen	1871–1947	77	57°10′N	02°06′W	27
Angmagssalik	1894–1950*	56	65°37′N	37°33′W	32
Archangel	1901–1954	54	64°35′N	40°30′E	3
Astrakhan	1881–1954	74	46°21′N	48°02′E	—14
Athens	1858–1950	93	37°58′N	23°43′E	107
Basle†	1755–1957	203	47°34′N	07°32′E	755
Belgrade	1888–1914, 1916–1918, 1920–1930, 1941–1950	51	44°48′N	20°27′E	138
Berezov	1881–1950*	60	63°56′N	65°04′E	39
Bergen	1816–1950	135	60°24′N	05°19′E	17
Berlin†	1769–1939	171	52°33′N	13°21′E	35
Berujsfjord	1883–1950	68	64°41′N	14°22′E	18
Bodo	1868–1950	83	67°17′N	14°24′E	21
Breslau†	1792–1939	148	51°07′N	17°02′E	147
Bucharest	1857–1950	94	44°25′N	26°06′E	82
Budapest	1780–1947	168	47°17′N	19°01′E	130
Catania	1892–1930, 1941–1950	49	37°30′N	15°05′E	65
Central England†	1698–1952	255			
Chernovitsy	1880–1915, 1921–1940	56	48°17′N	25°56′E	225
Copenhagen†	1768–1776, 1782–1788, 1798–1940	159	55°41′N	12°36′E	5
De Bilt	1706–1945	240	52°06′N	05°17′E	8

Station	Period	No. of Years	Lat.	Long.	Height in metres
Edinburgh†	1764–1940	177	55°55′N	03°11′W	76
Elabuga	1901–1954*	53	55°46′N	52°04′E	90
Fort Shevchenko	1882–1918, 1921–1954*	70	44°33′N	50°15′E	—23
Frankfurt	1835–1950	116	50°07′N	08°41′E	102
Funchal	1880–1950	71	32°37′N	16°54′W	25
Gibraltar	1852–1862, 1864–1884, 1886–1939, 1941–1950*	94	36°06′N	05°21′W	16
Gjesvar	1878–1926	49	71°06′N	25°22′E	7
Godthaab	1875–1950*	74	64°11′N	51°43′W	9
Greenwich†	1764–1958	195	51°28′N	00°00′	49
Grimsey	1874–1930, 1941–1950*	64	66°33′N	18°01′W	22
Gutersloh	1835–1920	86	51°54′N	08°23′E	76
Haparanda	1860–1950	91	65°50′N	24°09′E	9
Helsinki	1829–1950	122	60°10′N	24°57′E	12
Horta	1902–1950	49	38°32′N	28°38′W	65
Hvar	1859–1918	60	43°10′N	16°26′E	20
Ivigtut	1879–1950*	68	61°12′N	48°10′W	5
Jakobshavn	1873–1950*	76	69°13′N	51°02′W	13
Jena	1770–1800, 1820–1935	147	50°54′N	11°35′E	163
Kazan	1881–1950	70	55°47′N	49°08′E	81
Kem Gorod	1901–1954	54	64°57′N	34°39′E	8
Kharkov	1901–1954*	51	50°00′N	36°14′E	140
Kiev	1901–1954	54	50°27′N	30°30′E	183
Klagenfurt	1813–1907, 1910–1947	133	46°38′N	14°19′E	448
Kola	1901–1954	54	68°53′N	33°01′E	5
Konigsberg	1851–1944	94	54°43′N	20°30′E	3
Krasnovodsk	1883–1898, 1900–1902, 1904–1918, 1921–1954*	68	40°00′N	52°59′E	—10
Kremsmunster	1815–1907, 1910–1947	131	48°03′N	14°07′E	388
Leningrad	1901–1954	54	59°58′N	30°18′E	4
Lisbon	1864–1950	87	38°43′N	09°08′W	95
Lvov	1901–1954	54	49°50′N	24°02′E	298
Madrid	1860–1919, 1921–1950	90	40°24′N	03°41′W	655
Malye Karmakuly	1901–1954*	46	72°23′N	52°42′E	15
Marseilles	1851–1940	90	43°18′N	05°23′E	75
Milan	1866–1936, 1941–1950	81	45°28′N	09°11′E	147
Moscow	1901–1954	54	55°50′N	37°33′E	167
Nantes	1881–1950	70	47°15′N	01°34′W	37
Nikolaewskoe	1881–1950	70	51°27′N	45°27′E	193
Novorossisk	1881–1885, 1888–1954	71	44°44′N	37°49′E	37
Obdorsk	1901–1954	54	66°31′N	66°36′E	35
Obir	1851–1944	94	46°30′N	14°29′E	2044
Odessa	1901–1954	54	46°26′N	30°46′E	43
Orenburg	1886–1954	69	51°45′N	55°06′E	109
Osijek	1882–1955	74	45°33′N	18°41′E	90
Oslo	1816–1950	135	59°55′N	10°43′E	25
Ostrov Dikson	1916–1954*	38	73°31′N	80°24′E	13
Palma	1865–1881, 1883–1950	83	39°33′N	02°42′E	35
Paris	1764–1866, 1874–1950	180	48°48′N	02°30′E	50
Perm	1883–1950	68	58°01′N	56°16′E	163
Ponta Delgada	1894–1950	57	37°44′N	25°40′W	22
Prague†	1775–1939	165	50°05′N	14°25′E	202
Riga	1901–1954	54	56°58′N	24°02′E	10

Station	Period	No. of Years	Lat.	Long.	Height in metres
Rome	1811–1823, 1825–1930, 1941–1950	129	41°54′N	12°29′E	63
Rostov na Donu	1901–1954	54	47°14′N	39°45′E	68
Santis	1883–1950	68	47°15′N	09°20′E	2500
Sassari	1883–1930	48	40°44′N	08°35′E	224
Shenkursk	1901–1954*	48	62°06′N	42°54′E	47
Sibiu	1851–1917, 1919–1950	99	45°47′N	24°19′E	419
Sletnes	1898–1940	43	71°05′N	28°14′E	7
Sonnblick	1886–1950	65	47°03′N	12°57′E	3107
Stalingrad	1901–1954	54	48°42′N	44°31′E	65
Stockholm	1756–1950	195	59°21′N	18°03′E	42
Stykkisholm	1873–1950	78	65°05′N	22°46′W	25
Sulina	1876–1950	75	45°09′N	29°40′E	2
Surgut	1885–1954	70	61°15′N	73°24′E	40
Sverdlovsk	1881–1954	74	56°50′N	60°38′E	284
Syktyvkar	1901–1954	54	61°40′N	50°51′E	130
Thorshavn	1872–1925, 1931–1950*	73	62°03′N	06°45′W	26
Tiflis	1881–1954	74	41°43′N	44°48′E	404
Tobolsk	1888–1954*	67	58°12′N	68°14′E	108
Trondheim†	1761–1946	186	63°26′N	10°25′E	133
Upernavik	1873–1950*	74	72°47′N	56°07′W	19
Uppsala	1856–1950	95	59°51′N	17°38′E	24
Ust Zylma	1901–1954	54	65°25′N	52°18′E	70
Valentia	1869–1950	82	51°56′N	10°15′W	14
Vestmanno	1884–1950	67	63°24′N	20°17′W	13
Vienna†	1775–1939	165	48°15′N	16°22′E	203
Vilna†	1781–1915, 1921–1938	153	54°41′N	25°18′E	148
Warsaw	1885–1935	51	52°13′N	21°01′E	133
Zametchino	1901–1954	54	53°30′N	42°37′E	133
Zurich	1864–1950	87	47°23′N	08°33′E	477

* Periods include short gaps.

† These stations were used for the preliminary investigation based on normals for the whole period mentioned on page 2.

THE RESULTS OF THE 5 × 5 ANALYSIS

For each station a total of $12 \times 21 = 252$ contingency tables were found. Each contingency table has 16 degrees of freedom so that, on the hypothesis that none of the variables are associated, only 5 per cent of the chi-squared values should exceed 26·30, 2 per cent 29·63, 1 per cent 32·00 and 0·1 per cent 39·25. Thus with 252 tables per station the 2 per cent value of chi-squared should be exceeded on about 5 occasions in the absence of any real association between any of the monthly temperatures at that station. The results, summarized according to lag, are given in Table II.

For lag 1 the number of tables which appear significant at the 2 per cent level is far beyond the chance expectation, so we may feel confident that most of these relationships are not due to chance. For lags 2–11 the numbers are generally above the chance expectation but not decisively so and for lags 12–21 we certainly cannot be sure that any associations found are not due to chance.

The tables for lag 1 in which chi-squared exceeded the 2 per cent level are listed in Table III.

TABLE II. *The number of 5×5 contingency tables of monthly mean temperature which appear significant at the 2 per cent level shown as a function of the lag (separation between the months). Results are pooled for 15 European stations for all permissible combinations of months.*

Lag	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Expected
No. of tables significant at 2 per cent level	38	5	8	4	5	3	8	6	5	4	6	3	4	2	2	6	2	3	2	3	2	3·6

TABLE III. *The strength of the association between the mean temperature in the month named and that of the month before, as measured by the value of chi-squared in a 5×5 contingency table. Only values exceeding the 2 per cent level are included and those exceeding the 0·1 per cent level are in italics.*

Station	Month	Chi-squared	Station	Month	Chi-squared
Basle	June	*41·73*	Copenhagen—*cont.*	August	*64·68*
	July	32·57		September	32·77
Bergen	February	30·39	Edinburgh	March	36·88
	March	31·95		September	*51·82*
	July	*41·48*	Prague	February	29·70
	August	35·01	Stockholm	February	36·92
De Bilt	March	*51·14*		March	*68·65*
	May	32·43		April	32·18
	September	*39·46*		July	35·67
Berlin	March	*43·79*	Trondheim	March	37·10
Breslau	August	29·78		April	30·62
	October	33·93		June	30·02
Central England	March	*53·05*		July	*49·32*
	April	36·00		August	35·76
	July	34·35		October	34·81
Copenhagen	February	36·64	Vienna	August	36·65
	March	*56·78*	Vilna	March	34·53
	April	33·14		April	*40·09*
	July	31·27		September	29·74

Note: No values reach the 2 per cent level at Greenwich or Jena

It appears that many of these chi-squared values greatly exceed the 2 per cent level, in fact over a quarter exceed the 0·1 per cent level and are quite unlikely to arise by chance even in an experiment as extensive as this one. By contrast, in the tables for lags 2–21 the values of chi-squared which exceeded the 2 per cent level did so by small margins and are not unlikely in this large experiment. The conclusion is quite definite that for certain stations in certain seasons there is a real association between the temperature anomalies in consecutive months whereas there is little evidence of any relationship between the anomalies in non-consecutive months.

The occurrence of high chi-squared values in different seasons is shown in Table IV.

TABLE IV. *The number of European stations (out of 15) in which the mean temperature in the month named shows a strong association with that of the month before, as judged by the chi-squared value.*

Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
0	4	9	5	1	2	6	5	4	2	0	0

Since there are 15 tables per month, the chance expectation of one chi-squared value exceeding the 2 per cent level is only 0·3 so that all these results are probably significant for the stations which have the high values. The actual frequencies for some of the interesting tables are given in the Appendix.

PATTERNS OF ASSOCIATION

We examined all the contingency tables listed in Tables III and IV and also those for lags exceeding lag 1 with significant chi-squared values. It appeared that the main pattern of association is one of persistence. To test this objectively we found, for each contingency table, the sum of frequencies on the leading diagonal divided by the total. When divided by 0·2, the value expected in an equally distributed table, the quotient gives us a crude index of persistence in value ranging from 0–1, the chance expectation, up to 5 for perfect association. This index was found for all tables with high chi-squared values and Table V shows some of the results.

TABLE V. *Frequency of occurrence of specified values of the persistence index for tables with high chi-squared values. Lag 1 results are compared with pooled results for lags 9–12.*

Persistence index	Lag 1				Lags 9–12		
	chi-squared				chi-squared		
	>39·25	39·25–32·00	32·00–29·63	29·63–26·30	>32·00	32·00–29·63	29·63–26·30
	frequency				*frequency*		
0·6–0·7	—	—	—	—	—	—	2
0·7–0·8	—	—	—	—	3	—	1
0·8–0·9	—	—	—	—	2	2	2
0·9–1·0	—	—	—	—	—	3	5
1·0–1·1	—	2	1	1	1	3	7
1·1–1·2	—	1	—	6	—	1	2
1·2–1·3	1	2	5	2	2	1	2
1·3–1·4	1	2	—	2	—	—	1
1·4–1·5	2	7	1	1	—	—	1
1·5–1·6	5	2	1	—	—	—	—
1·6–1·7	1	2	—	—	—	—	—
1·7–1·8	2	—	—	—	—	—	—

This shows that while the control sample for lags 9–12 shows no preference for an index exceeding unity, the high chi-squared values for lag 1 have the index greater than unity, and broadly, the larger the value of chi-squared the greater the excess.

The results are presented somewhat differently in Table VI.

TABLE VI. *Relation between lag and the value of the persistence index for all tables for which chi-squared exceeds the 5 per cent level. 15 stations, 180 5 × 5 tables per lag. "Persistent" implies an index greater than unity.*

Lag	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
	No. of cases																				
Persistent	50	12½	9½	7½	4	10	15	5½	5	8	4	4	6	5	3	6	2½	4	2	4	1
Antipersistent	0	2½	3½	2½	5	5	2	3½	5	4	7	4	8	2	4	4	4½	4	5	3	9

It is clear that for lag 1 there is decisive evidence of a preference for persistence, but it is rather surprising to find the same preference in a much weaker form for lags up to perhaps 8 months. For greater lags the proportions are much more even. However, with so many contingency tables to choose from we may expect about 9 for each lag to have chi-squared values above the 5 per cent level, and there is no reason to expect these to be persistent rather than otherwise. A fair conclusion is that there is a tendency for persistence which is often very strong from one month to the next, but which may extend in a progressively weaker form up to a separation of about 8 months.

EXTENDING THE ANALYSIS BY MEANS OF 3 × 3 TABLES

The chi-squared values for the 15 stations for which 5 × 5 tables could be made were plotted on maps, one for each month of the year for any chosen lag. It appeared that high values of chi-squared tended to occur in definite areas in different months but that with so few stations the patterns were very incomplete. The computations were repeated using 3 × 3 tables and the much denser network of about 100 stations with 60–80 years' data. The resulting patterns of high chi-squared values confirmed and extended those shown by the original 15 stations, and only the more complete results from the 3 × 3 tables are described.

In a 3 × 3 table the 5 per cent level for chi-squared is 9·49, the 1 per cent level 13·28 and the 0·1 per cent level 18·47, and isopleths of these values are shown for the 12 calendar months in Figures 1–12. Before examining these figures, however, we should consider some typical 3 × 3 tables of which examples are given in Tables VII(*a*)–(*d*). These four cases are fully worked showing, besides the observed frequency, the expected frequency and the contribution to chi-squared for every cell.

Table VII(*a*) gives the February–March relationship for Berlin, 1770–1939; the chi-squared value is 12·99 which is between the 2 per cent and the 1 per cent levels of significance. There is an excess of cases in the cold February–cold March (C–C) cell, and a deficiency in the cold February–warm March (C–W) cell and the contributions by these two cells to chi-squared (in italics) make up over two-thirds of the total. It follows that a cold February at Berlin provides a useful indication as to the probable temperature anomaly in March, whereas a medium or warm February provides none. This is a good example of a relationship which would be obscured if the association had been tested by means of a correlation coefficient, and it shows the value of the chi-squared calculation in directing attention to the really interesting feature of the table.

Table VII(*b*) gives the March–April relationship for Berlin for 1770–1939. The total chi-squared value is well below even the 5 per cent significance level but there are frequencies slightly above expectation in the C–C and W–W cells, and slightly below expectation in the C–W and W–C cells and these make the largest contributions to total chi-squared. The suggestion that like will follow like is, however, extremely slight since if the tendency continues indefinitely with the strength shown, then we will have to wait 500 years or so before we can be reasonably sure that it is not a matter of chance.

Table VII(*c*) gives the March–April relationship for Helsinki 1829–1950. The highly significant chi-squared value is due mainly to frequencies above expectation in the C–C and W–W cells, and below expectation in the C–W and W–C cells. This is a symmetrical type of persistence in which either a cold or a warm March provides useful evidence as to the temperature anomaly in April.

Table VII(*d*) shows the March–April relationship for Leningrad 1901–1954. The total chi-squared value is quite insignificant and the discrepancies in the individual cells, unlike those in Table VII (*b*), do not suggest a pattern of persistence or anything else. The contrast with Helsinki also is striking, in view of the comparative proximity of the stations.

TABLE VII(*a*). *Typical example of 3×3 contingency tables showing expected frequencies and contributions to chi-squared for Berlin 1770–1939, February to March, lag 1.*

			February			
			Cold	Medium	Warm	Total
March	Cold	O	27·0	17·0	21·0	65
		E	17·6	21·0	26·4	
		C	*5·02*	0·76	1·10	
	Medium	O	13·0	20·0	23·0	56
		E	15·1	18·2	22·7	
		C	0·29	0·18	0·00	
	Warm	O	6·0	18·0	25·0	49
		E	13·3	15·8	19·9	
		C	*4·00*	0·31	1·31	
	Total		46	55	69	170

Chi-squared = 12·99

O = observed frequency, E = expected frequency on the hypothesis that the quantities measured are unrelated, C = contribution to chi-squared.

TABLE VII(*b*). *Typical example of 3×3 contingency tables showing expected frequencies and contributions to chi-squared for Berlin 1770–1939, March to April, lag 1.*

			March			
			Cold	Medium	Warm	Total
April	Cold	O	24·0	17·0	13·0	54
		E	20·65	17·8	15·55	
		C	*0·54*	0·04	*0·42*	
	Medium	O	26·0	19·0	17·0	62
		E	23·7	20·4	17·9	
		C	0·22	0·10	0·05	
	Warm	O	15·0	20·0	19·0	54
		E	20·65	17·8	15·55	
		C	*1·55*	0·27	*0·76*	
	Total		65	56	49	170

Chi-squared = 3·94

O = observed frequency, E = expected frequency on the hypothesis that the quantities measured are unrelated, C = contribution to chi-squared.

TABLE VII(*c*). *Typical example of 3×3 contingency tables showing expected frequencies and contributions to chi-squared for Helsinki 1829–1950, March to April, lag 1.*

			March: Cold	March: Medium	March: Warm	Total
April	Cold	O	15·0	8·0	5·0	28
		E	8·50	9·90	9·60	
		C	*4·97*	0·37	*2·21*	
	Medium	O	14·0	20·0	13·0	47
		E	14·25	16·55	16·2	
		C	0·00	0·72	0·63	
	Warm	O	8·0	15·0	24·0	47
		E	14·25	16·55	16·2	
		C	*2·75*	0·15	*3·78*	
Total			37	43	42	122

Chi-squared = 15·59

O = observed frequency, E = expected frequency on the hypothesis that the quantities measured are unrelated, C = contribution to chi-squared.

TABLE VII(*d*). *Typical example of 3×3 contingency tables showing expected frequencies and contributions to chi-squared for Leningrad 1901–1954, March to April, lag 1.*

			March: Cold	March: Medium	March: Warm	Total
April	Cold	O	2·0	7·0	3·0	12
		E	3·34	5·11	3·55	
		C	0·54	*0·70*	0·08	
	Medium	O	6·0	7·0	3·0	16
		E	4·5	6·81	4·74	
		C	0·54	0·00	0·64	
	Warm	O	7·0	9·0	10·0	26
		E	7·21	11·08	7·71	
		C	0·01	0·39	0·68	
Total			15	23	16	54

Chi-squared = 3·59

O = observed frequency, E = expected frequency on the hypothesis that the quantities measured are unrelated, C = contribution to chi-squared.

These examples show that different 3×3 contingency tables show quite different features which cannot be summed up in any one statistic. There is a general tendency for the high values of chi-squared to go with relatively strong month-to-month persistence but the nature of the relationship can only be seen by examining the individual tables. It is out of the question for us to examine all tables, or even all significant tables, in the same way as we have treated these four examples, but in the Appendix we give the actual frequencies for all 3×3 tables in which chi-squared exceeds the 0·1 per cent level and list the months and stations for which chi-squared exceeds the 2 per cent level.

In Figures 1–15, the isopleths enclosing the high values of chi-squared can be regarded roughly as showing the areas where the evidence for some sort of month-to-month persistence is strongest, but are perhaps better looked on as separating the areas in which month-to-month temperature relationships will repay further attention. The stations with 150–200 years' data provide stronger evidence than those with shorter records, and were given more weight when the isopleths were drawn.

Charts similar to Figures 1–12 were drawn for each month of the year for lags 2–6, that is, 60 charts in all. Most of these did *not* show any well defined patterns and only two seem worth inclusion, namely, Figure 13, February–April and Figure 14, January–April. Figure 15, December–February, is shown for comparison as typical of the majority of these charts which show nothing which may not be due to chance. Figures 1–14 will be discussed in turn.

December–January (see Figure 1)

There is an area of strong association extending from England and south Scotland through Denmark and south Sweden to Karesuando, the highest chi-squared value being at Stockholm. It does not include Valentia, Aberdeen or the extreme north of Norway, nor does it extend far inland. Other smaller and less definite areas cover the Azores and Madeira, part of west Greenland and a zone extending across south Russia from Kharkov to Orenburg.

January–February (see Figure 2)

The Britain to Baltic area of association is again present, but this time does not extend farther north than Haparanda, the highest value being at Copenhagen. Valentia and Greenwich are outside the area. There is a strong association in a triangle of the continent with corners at Berlin, Milan and Budapest, and also at Catania and Sassari. Another area of association covers part of south Russia including Stalingrad and the Caucasus and another covers all west Greenland.

February–March (see Figure 3)

There is a very large area of association covering most of Europe west of Russia apart from most of France and Spain. Other areas cover most of west Greenland and part of south Russia centred on Astrakhan. The area of strongest association seems to extend from Britain to Copenhagen and Stockholm.

March–April (see Figure 4)

There is still an area of association from central England to Stockholm with an extension across southern Russia to north-west Siberia. Much smaller areas occur over Lisbon and Gibraltar, central Italy and west Greenland.

April–May (see Figure 5)

There is an area of association over the Baltic and another centred near Gibraltar.

May–June (*see Figure* 6)

One area covers Scotland and most of Scandinavia, while others are over Iceland, west Greenland, north Russia and the Azores. Several Mediterranean stations show association.

June–July (*see Figure* 7)

One area includes central England and south Scandinavia, others include the Azores and Iceland and most Mediterranean stations.

July–August (*see Figure* 8)

There is association at all stations bordering the Atlantic or south Baltic, but not much over the continent except for an area in the Danube valley.

August–September (*see Figure* 9)

The main area includes Britain and south Scandinavia, but there are other small areas.

September–October (*see Figure* 10)

The main area is over south Russia, but there are several other small weak areas.

October–November (*see Figure* 11)

There is a small area in central Russia, but otherwise only at isolated stations. These patterns are so much weaker than those for any of the other months as to suggest that November is the natural start of the year, as regards thermal relationships in the area considered.

November–December (*see Figure* 12)

There are well marked areas over the Baltic and in south Russia agreeing quite well with those which follow in Figure 1.

February–April (*see Figure* 13)

A well marked area covers most of Scandinavia and the east coast of the Baltic Sea, and there is a much smaller one over the Alps.

January–April (*see Figure* 14)

An area of association extends from Finland through Poland and east Germany to the Ukraine. This area of association, like the preceding one, has the nature of persistence.

December–February (*see Figure* 15)

The stations with high chi-squared values are all quite isolated, and in number only slightly exceed the chance expectation. We have not tried to establish the significance of relations of this type, since we have so much more promising material, but even here it is interesting to note that nearly all the high chi-squared values arise from tables which give evidence of persistence.

COMMENTS AND CONCLUSIONS

The first impression left by examination of Figures 1–14 is that the persistence of monthly mean temperature anomaly is associated with certain fairly definite areas and seasons, and not with others. For example, south Scandinavia is involved in 10 of the 12 months and in 9 of these the area of association extends to some part of the British Isles. Some of the west Greenland stations and the area represented by the Azores and Madeira are each involved in 9 of the 12 months, while the part of Russia represented by Moscow and Leningrad does not seem to be involved at all. We cannot be as sure about the relations over Russia as we can elsewhere because the observational records are so much shorter, but many of the continental tables do not give even a suggestion of persistence.

Bearing in mind that the occurrence of warm and cold spells straddling the end of the month might be expected to impose some measure of persistence between any pair of months at any station, this negative result is almost as surprising as the others. It suggests that at Moscow, Leningrad and the continental areas generally, the temperature anomaly at the beginning or end of the month is almost uncorrelated with the monthly mean anomaly, and this can only be the case if the temperature oscillations of largest amplitude have periods considerably less than a month.

By contrast, the regions of high persistence nearly all appear to be associated with water, with freezing or breaking sea ice, or with the extension or decrease of snow cover. Obviously there is no one process leading to persistence, but there are a number, perhaps depending on the local inertia resulting from the presence of water, which in some way cause certain fringe areas to differ from the continental masses.

Another feature is that sharp gradients occur between neighbouring stations. When we compare, for example, Edinburgh and Aberdeen, or Stockholm and Uppsala we generally find that the station with the longer record has the higher chi-squared value, which is as it should be; but not all the discrepancies can be explained in this way, nor can the differences between for example, Berlin and Breslau, or Prague and Vienna, or Helsinki and Leningrad. The conclusion must be either that the associations depend on mainly large-scale circulation processes and that these processes are confined in their working to very definite tracks and limits, or that the anomalies do *not* depend mainly on large-scale processes, but are affected also by local processes such as the local distribution of land and water affecting, say, Leningrad and Uppsala as opposed to Helsinki and Stockholm, or the ground configuration affecting Prague as opposed to Breslau and Vienna.

The pattern of association shows a seasonal variation which is weak between the months of September, October, November and December, and also between April and May, but is stronger in the periods from December to April and from May to September. It seems that the year divides itself into two seasons, each with limited internal coherence in some areas, the major break being in the autumn. When we consider months which are separated by one or more months, there are only two relationships of which the reality is established beyond doubt, and these also are present only in certain areas.

It is evident that in many cases the relations are strong enough to be useful for long-range forecasting; for example Table VII(*a*) shows that after a cold February at Berlin the probability of a cold March is 59 per cent compared with a chance probability of 38 per cent. However, results such as this depend on the definitions of the terms "cold" and "warm" and their practical application cannot be examined in a general paper.

This large investigation entailing the examination and testing of over 10,000 contingency tables has thus produced mainly negative results, but it has gone some way towards its main object in outlining the field within which more sophisticated investigations are likely to prove worthwhile.

ACKNOWLEDGEMENTS

Acknowledgement is due to all the staff of the Synoptic Research Division who have co-operated in this work, and in particular to Mrs. J. Cattle who keeps the library of data tapes and carried out most of the routine electronic calculation, and to Mrs. B. Brown who did most of the hand calculations.

Note on interpretation of Figures

The anomalies, which are measured from a normal adjusted for climatic change, are plotted on a 3×3 contingency table using data for the longest possible period of years. A value of chi-squared much exceeding the chance expectation affords *prima facie* evidence of association and the isopleths which correspond to the 5 per cent, 1 per cent and 0·1 per cent significance levels indicate the regions where chi-squared is high. The actual values of the more highly significant results are given in the Appendix.

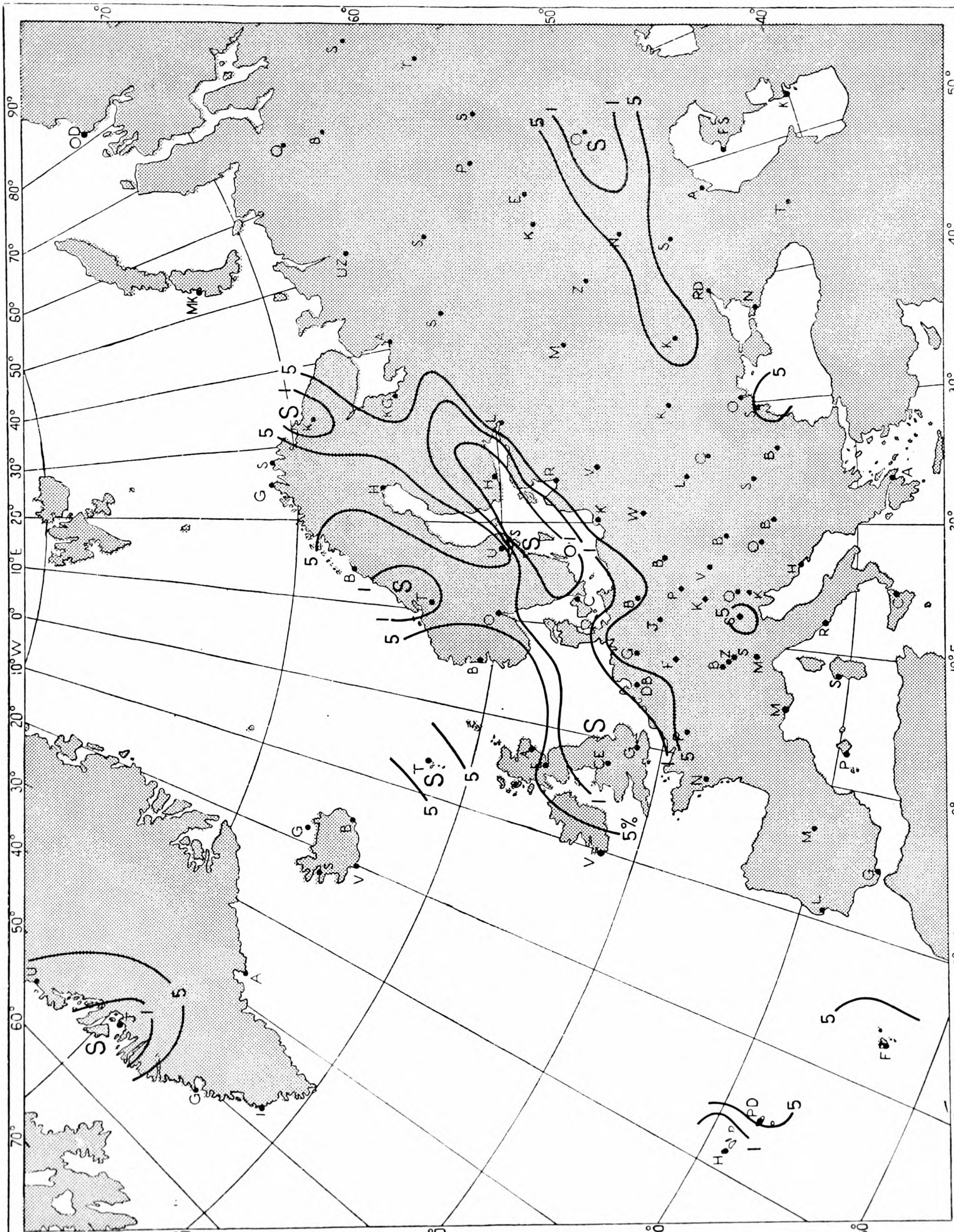

FIGURE 1. Chart showing the strength of the evidence of association between the temperature anomalies in December and January in Europe and the eastern Atlantic. For further description see note on page 14.

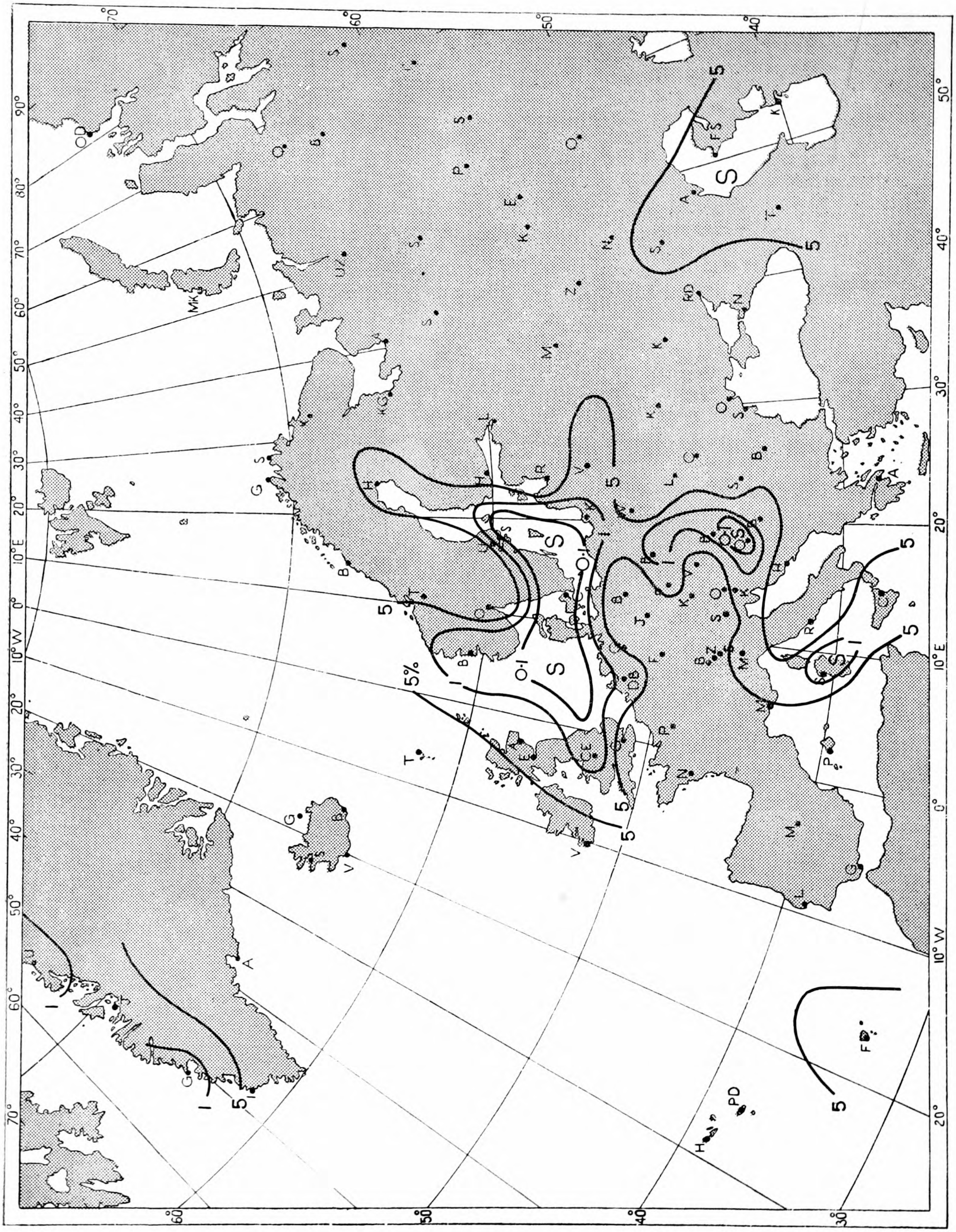

FIGURE 2. Chart showing the strength of the evidence of association between the temperature anomalies in January and February in Europe and the eastern Atlantic. For further description see note on page 14.

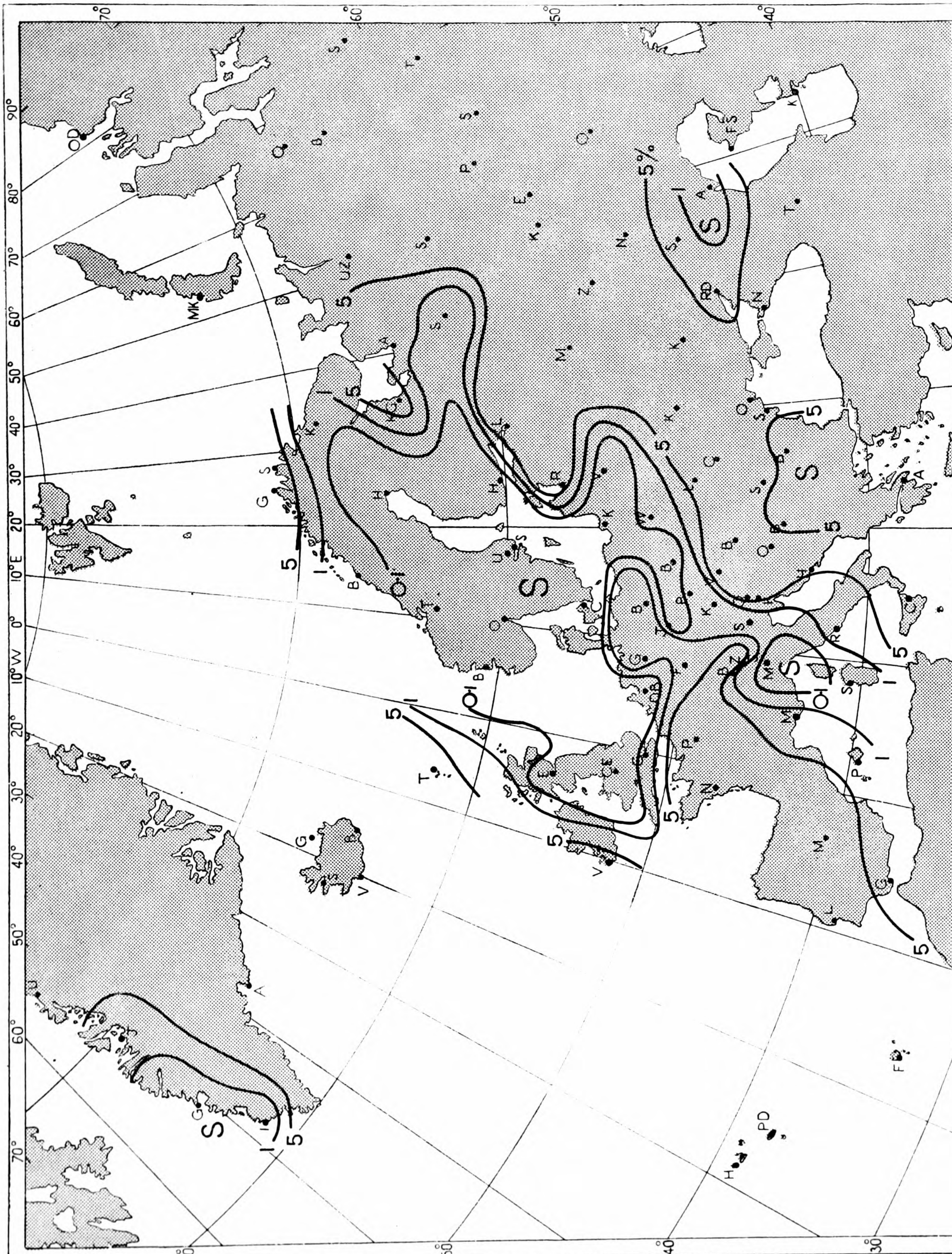

FIGURE 3. Chart showing the strength of the evidence of association between the temperature anomalies in February and March in Europe and the eastern Atlantic. For further description see note on page 14.

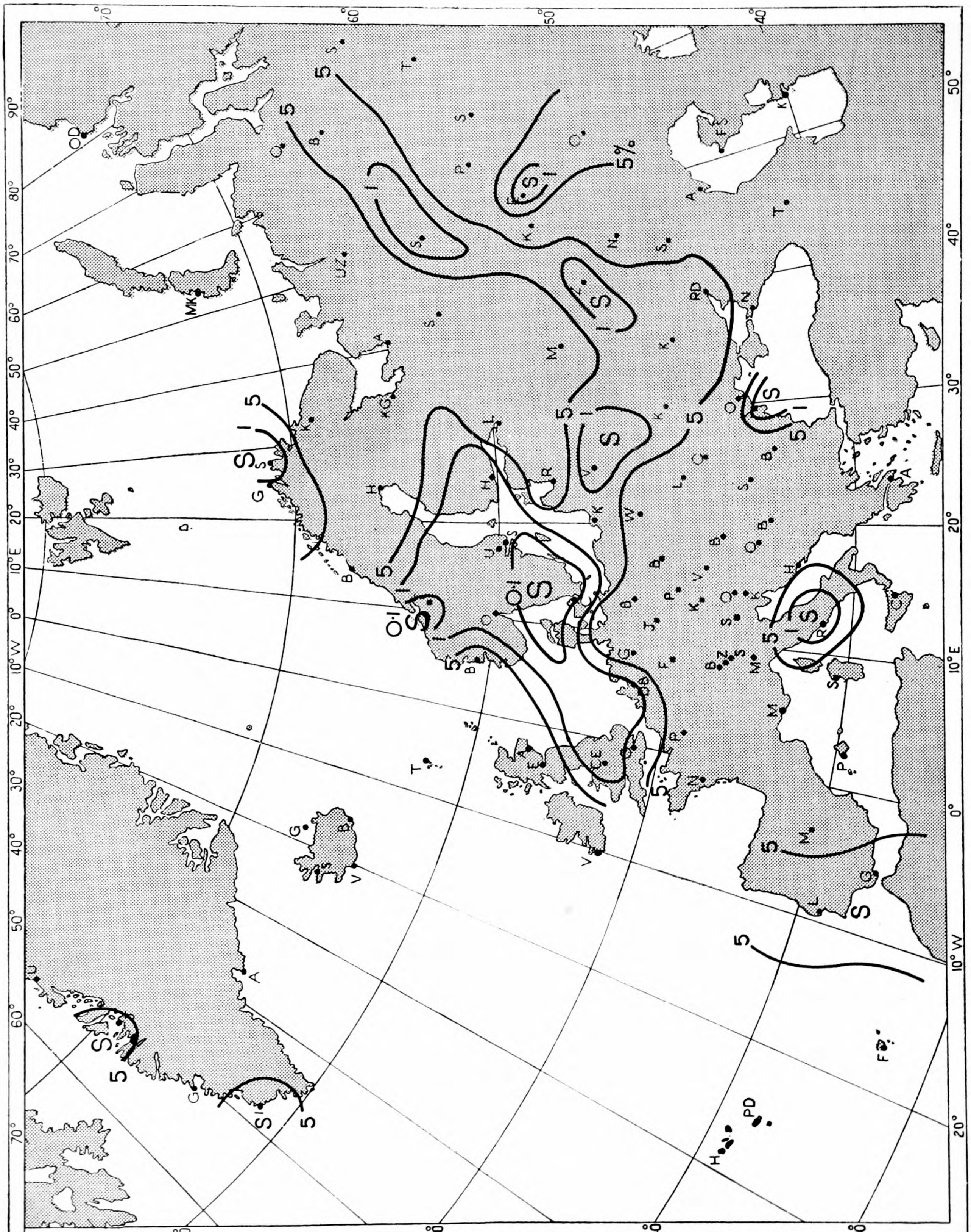

Figure 4. Chart showing the strength of the evidence of association between the temperature anomalies in March and April in Europe and the eastern Atlantic. For further description see note on page 14.

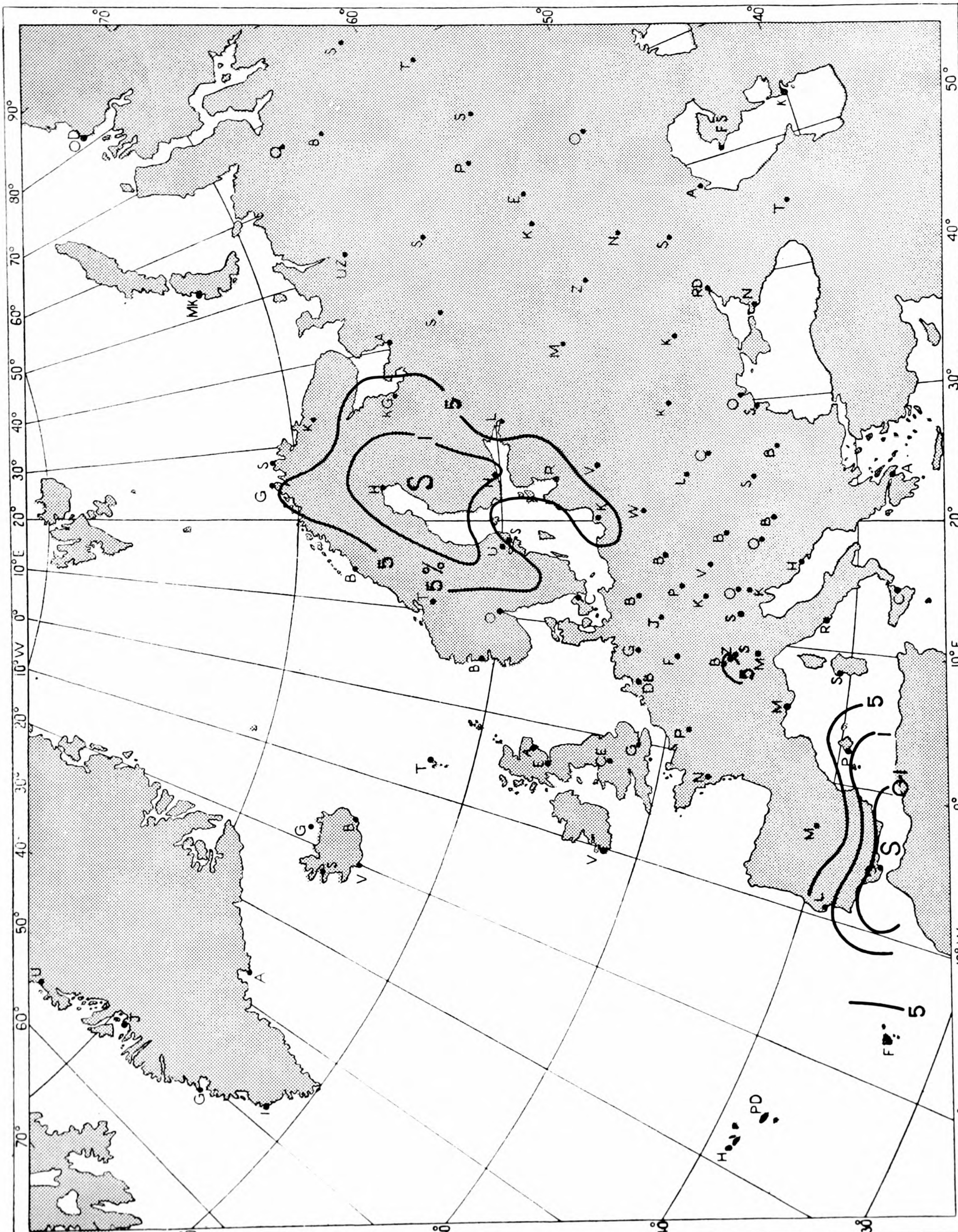

FIGURE 5. Chart showing the strength of the evidence of association between the temperature anomalies in April and May in Europe and the eastern Atlantic. For further description see note on page 14.

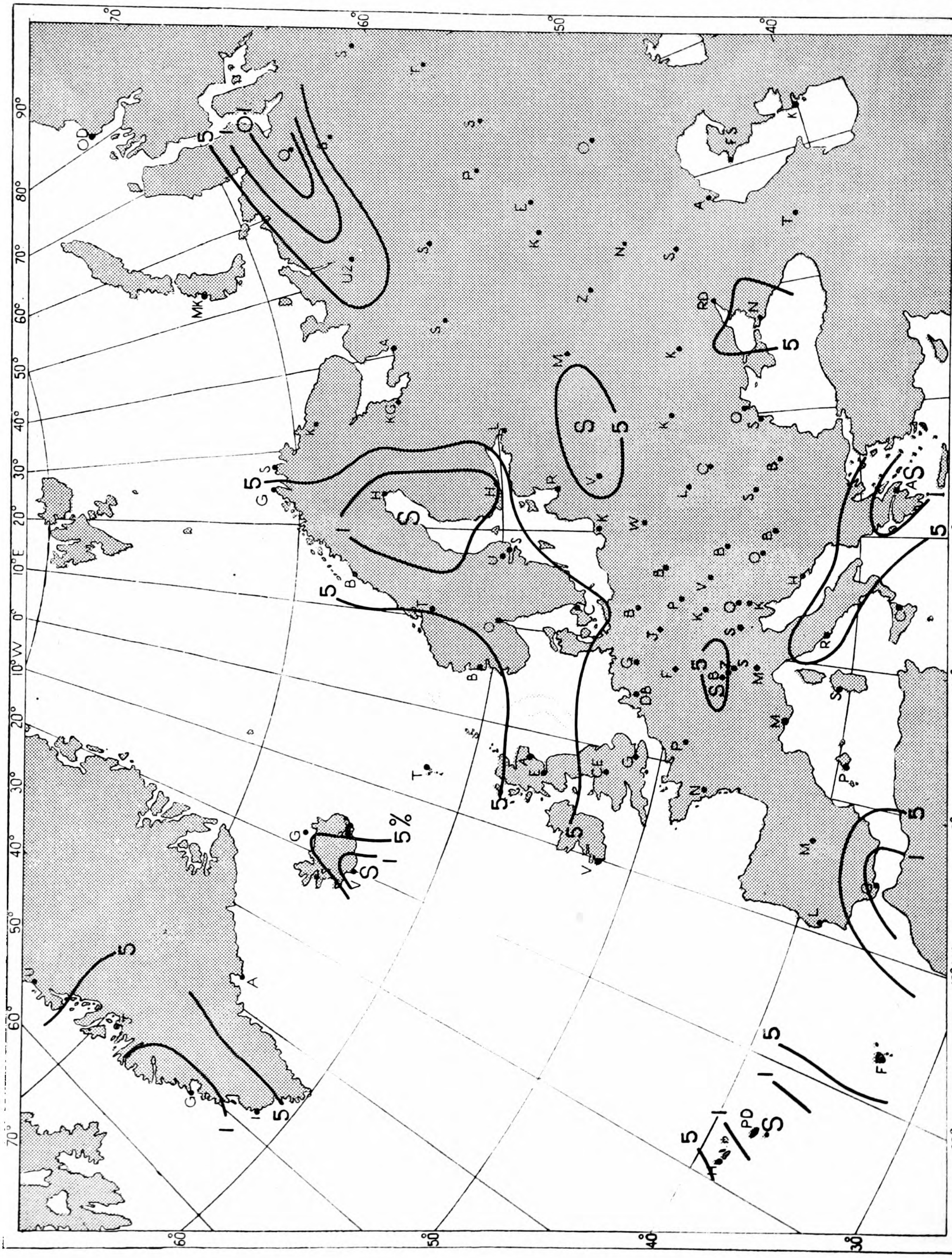

FIGURE 6. Chart showing the strength of the evidence of association between the temperature anomalies in May and June in Europe and the eastern Atlantic. For further description see note on page 14.

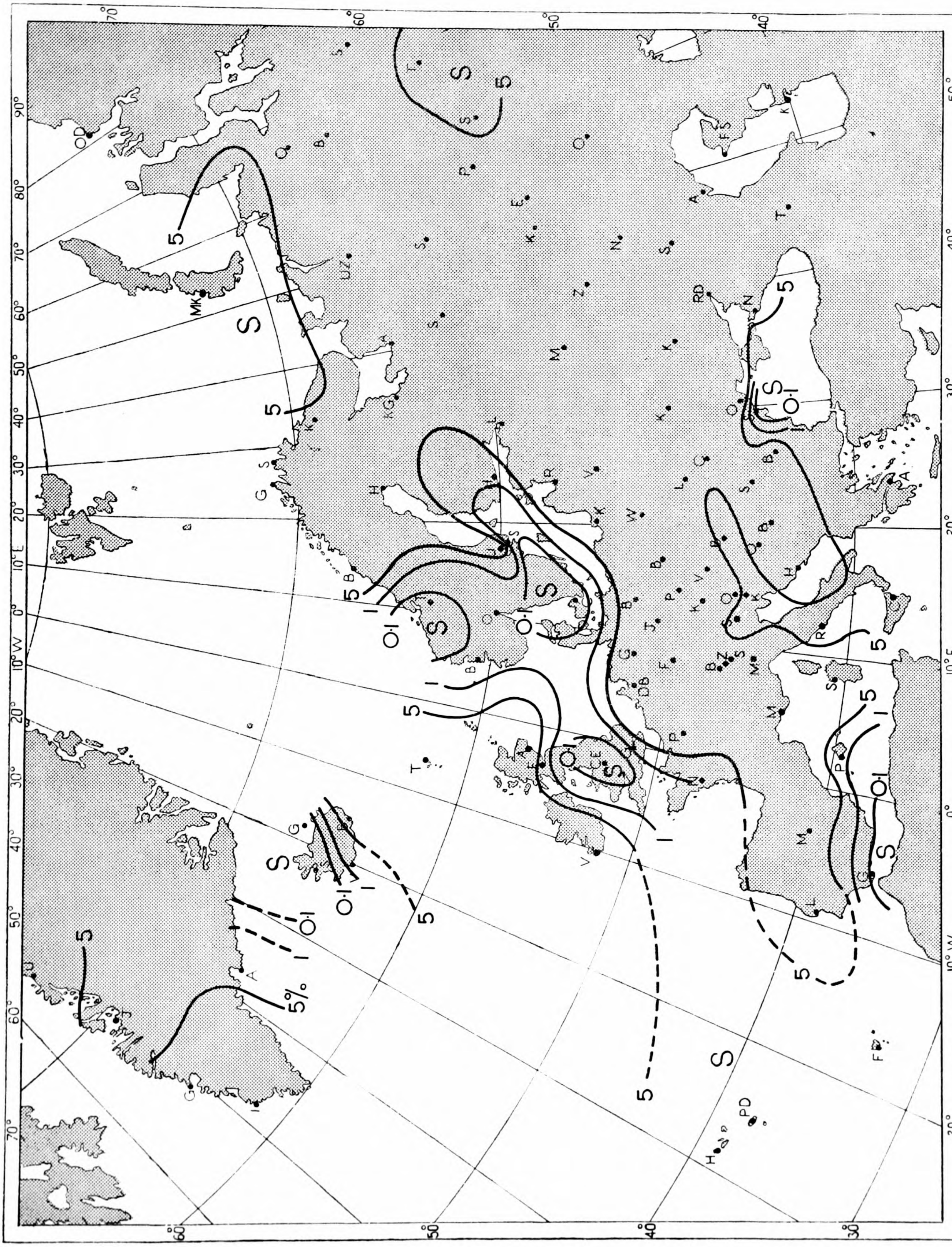

FIGURE 7. Chart showing the strength of the evidence of association between the temperature anomalies in June and July in Europe and the eastern Atlantic. For further description see note on page 14.

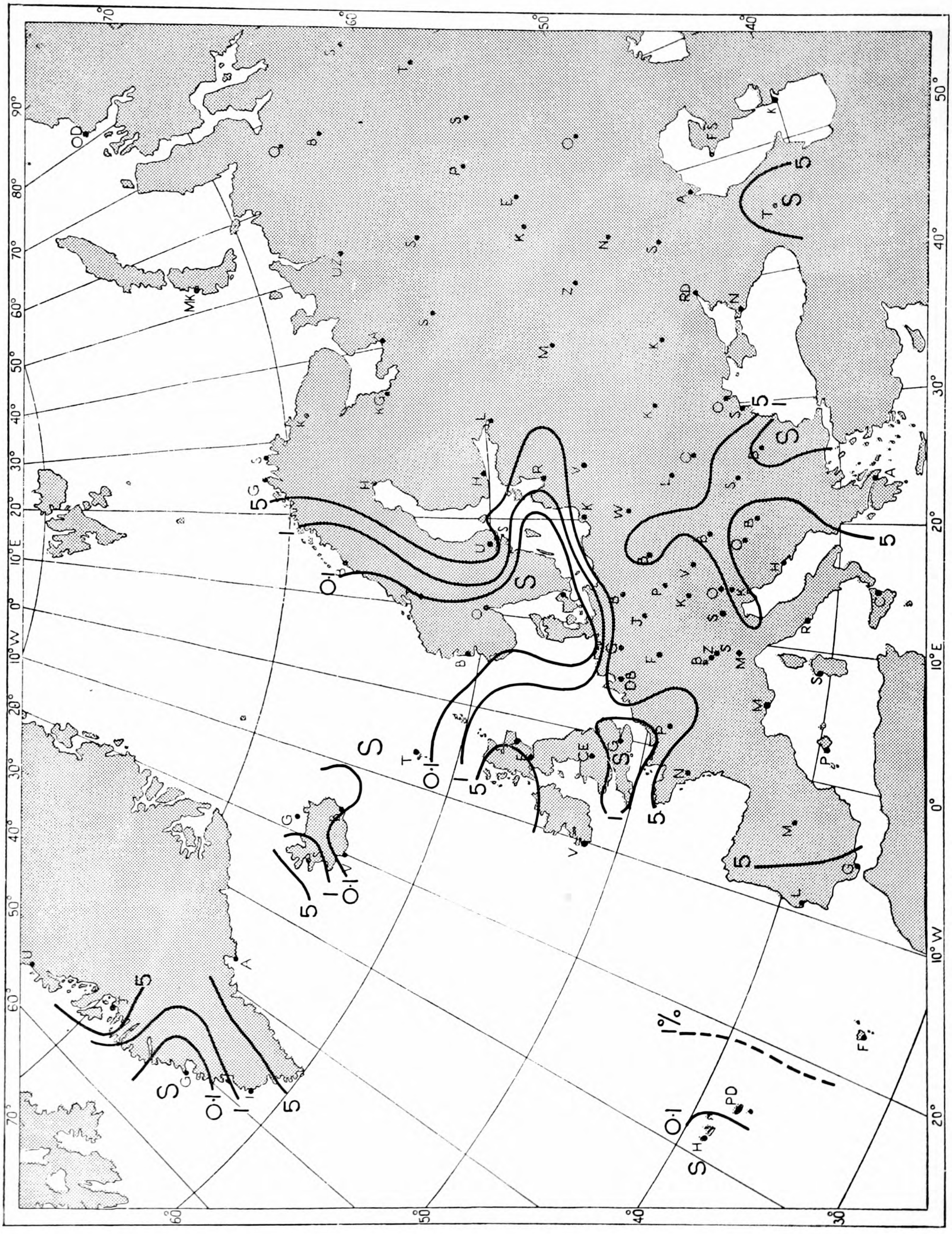

FIGURE 8. Chart showing the strength of the evidence of association between the temperature anomalies in July and August in Europe and the eastern Atlantic. For further description see note on page 14.

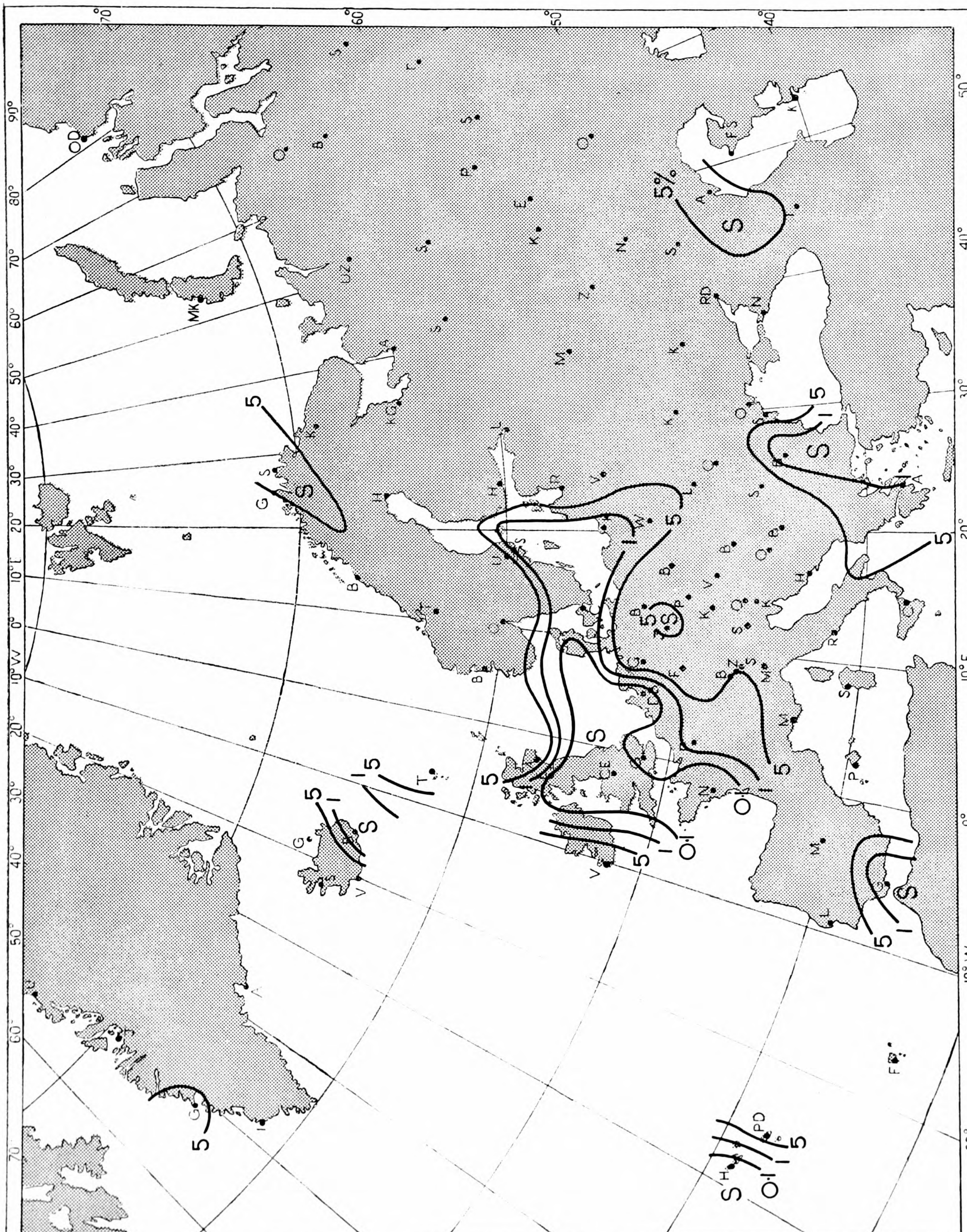

FIGURE 9. Chart showing the strength of the evidence of association between the temperature anomalies in August and September in Europe and the eastern Atlantic. For further description see note on page 14.

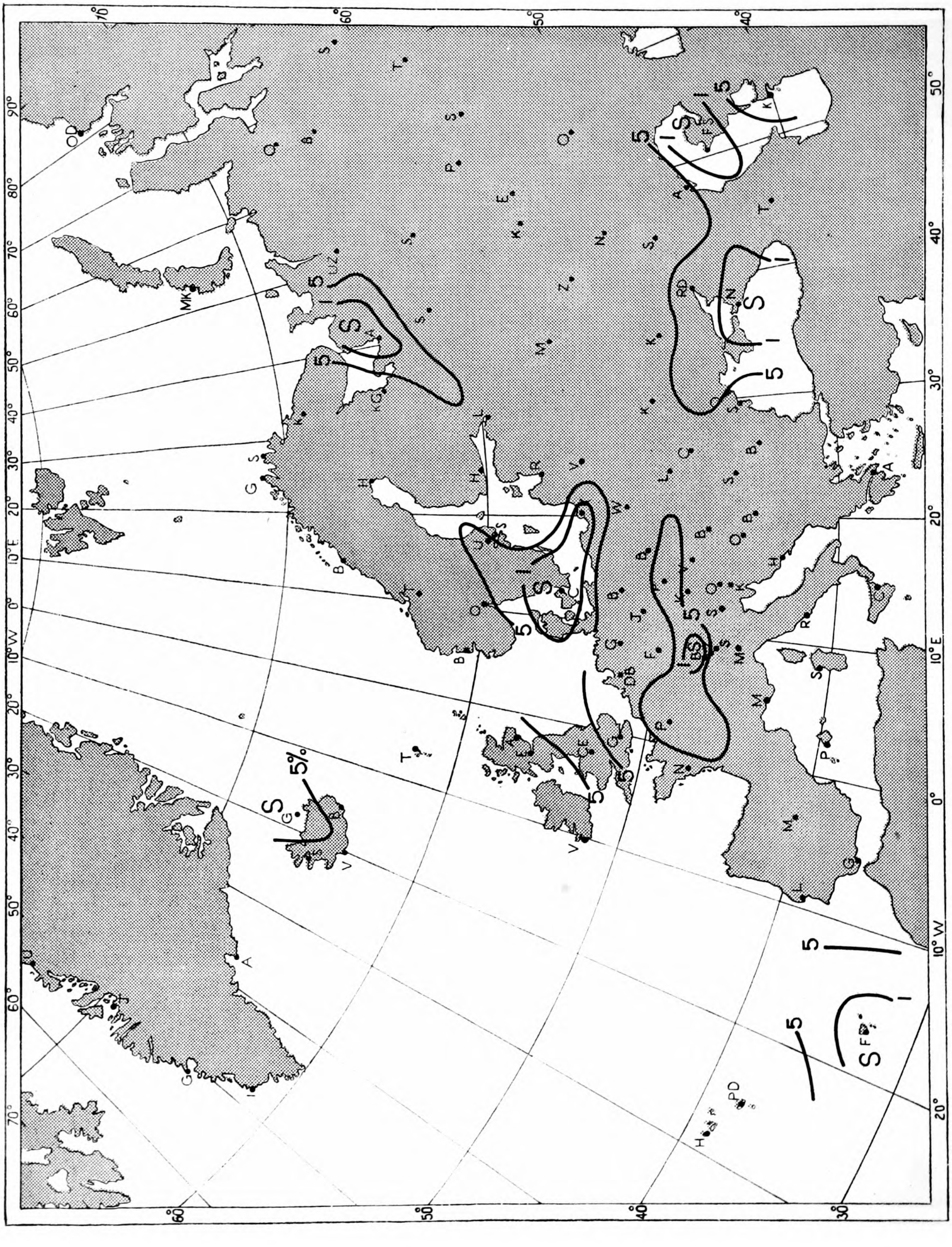

Figure 10. Chart showing the strength of the evidence of association between the temperature anomalies in September and October in Europe and the eastern Atlantic. For further description see note on page 14.

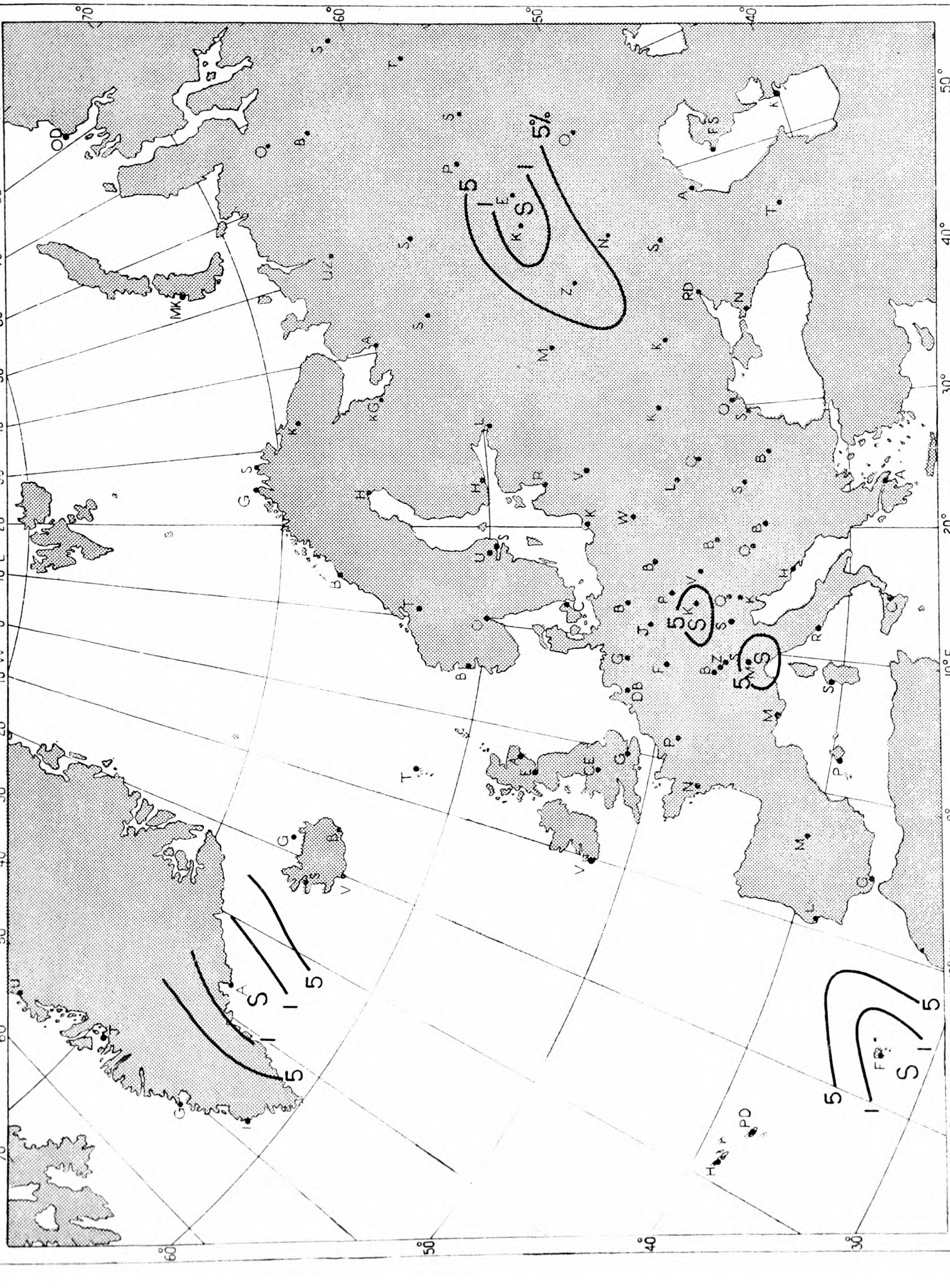

FIGURE 11. Chart showing the strength of the evidence of association between the temperature anomalies in October and November in Europe and the eastern Atlantic. For further description see note on page 14.

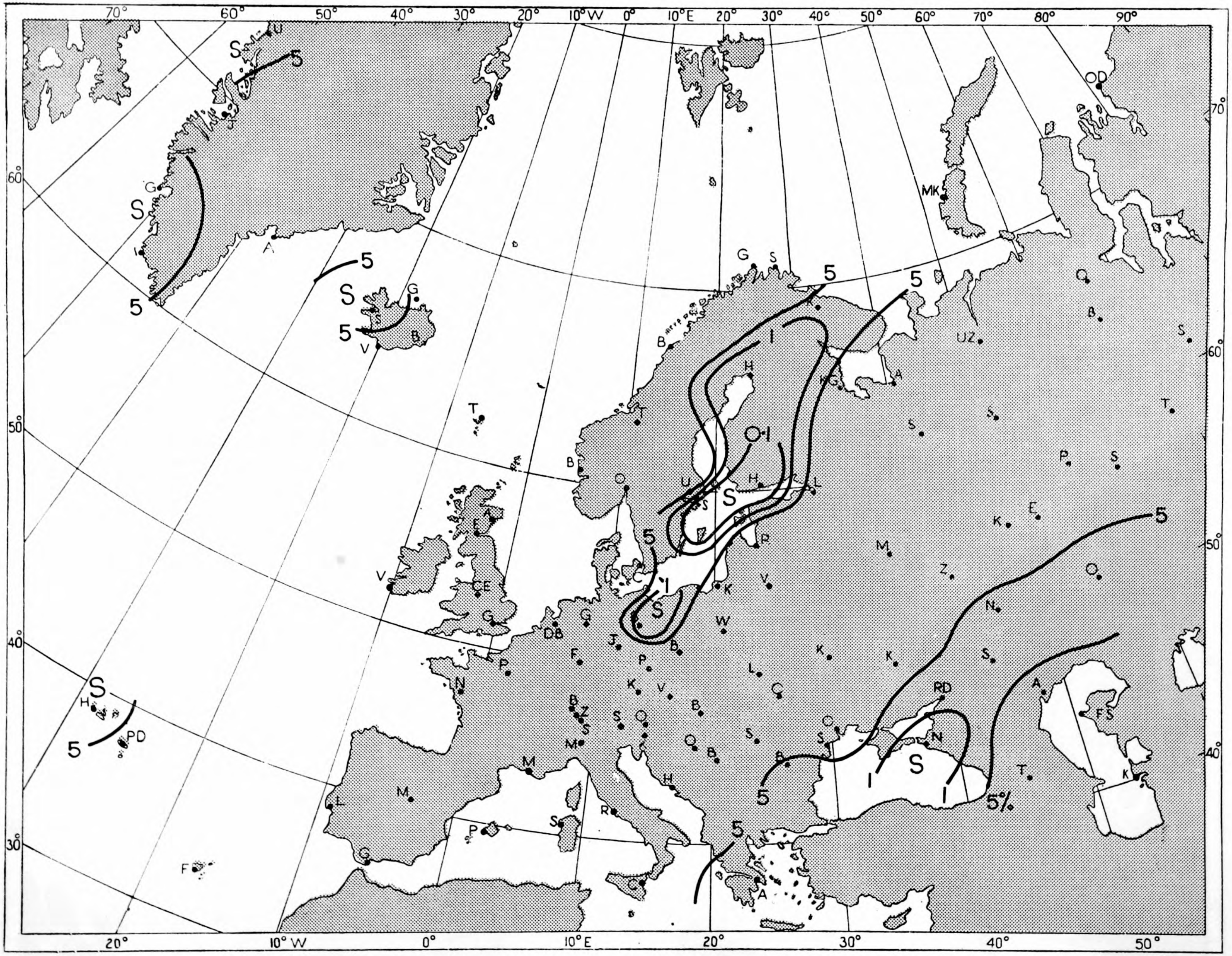

FIGURE 12. Chart showing the strength of the evidence of association between the temperature anomalies in November and December in Europe and the eastern Atlantic. For further description see note on page 14.

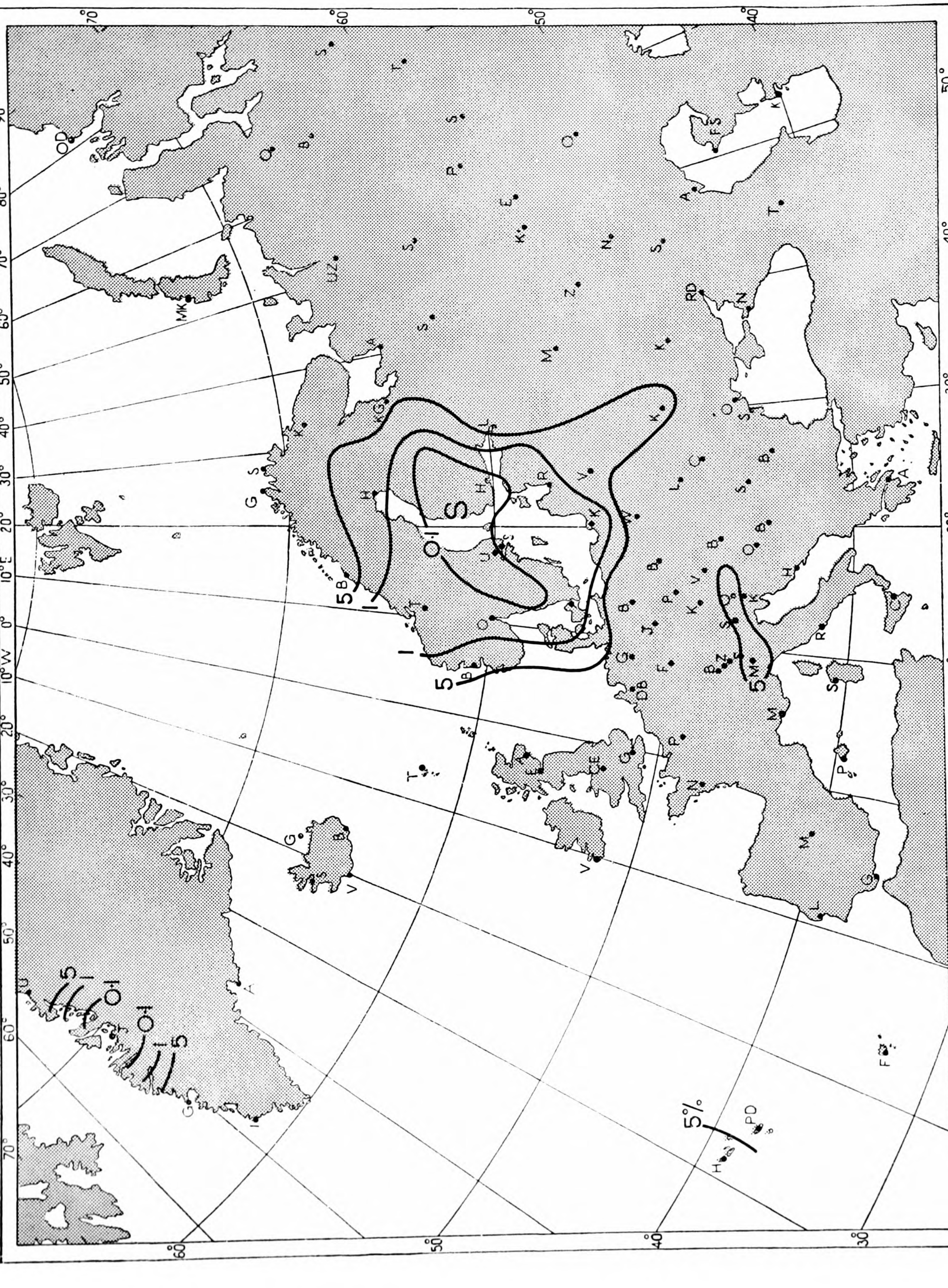

FIGURE 13. Chart showing the strength of the evidence of association between the temperature anomalies in February and April in Europe and the eastern Atlantic. For further description see note on page 14.

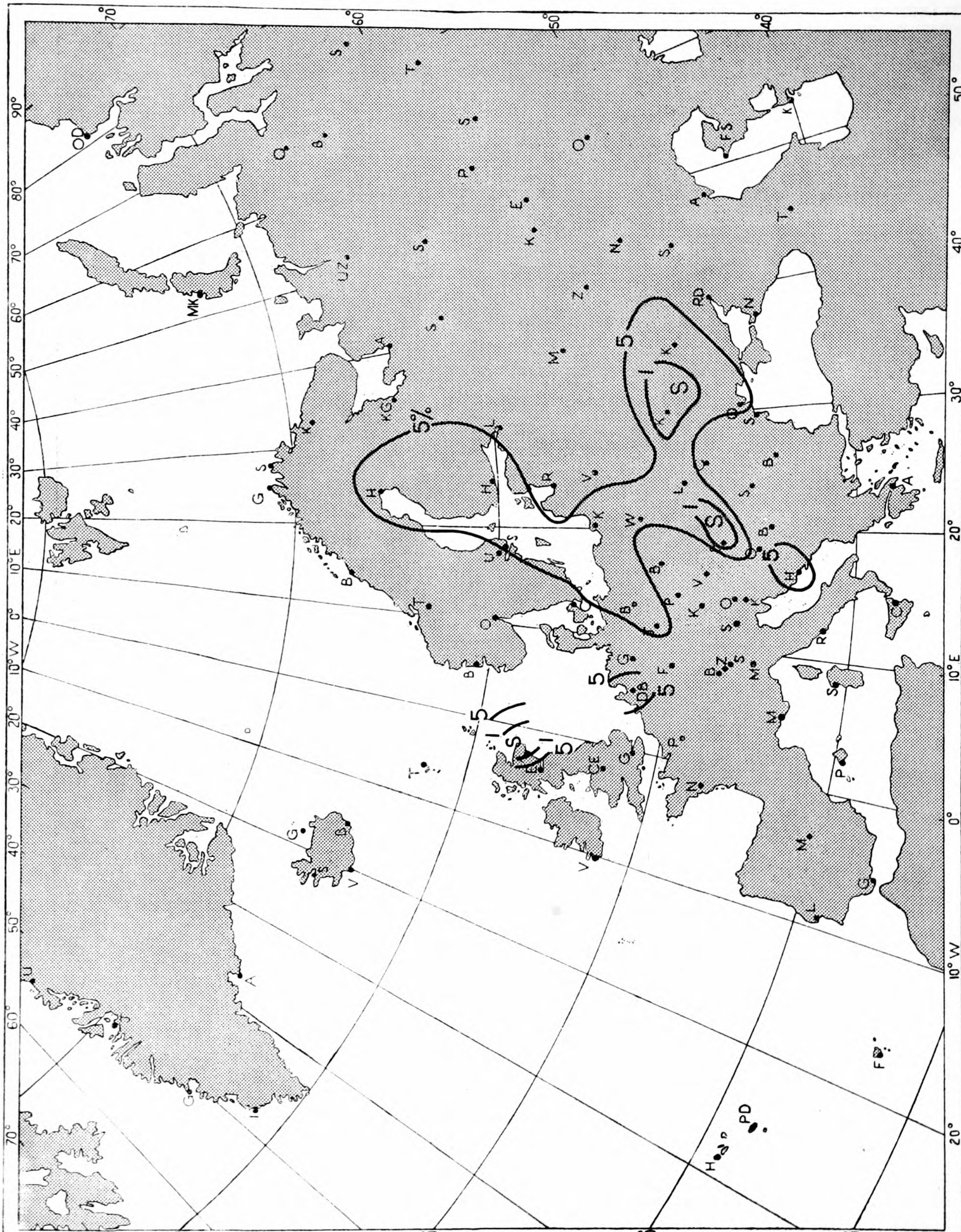

FIGURE 14. Chart showing the strength of the evidence of association between the temperature anomalies in January and April in Europe and the eastern Atlantic. For further description see note on page 14.

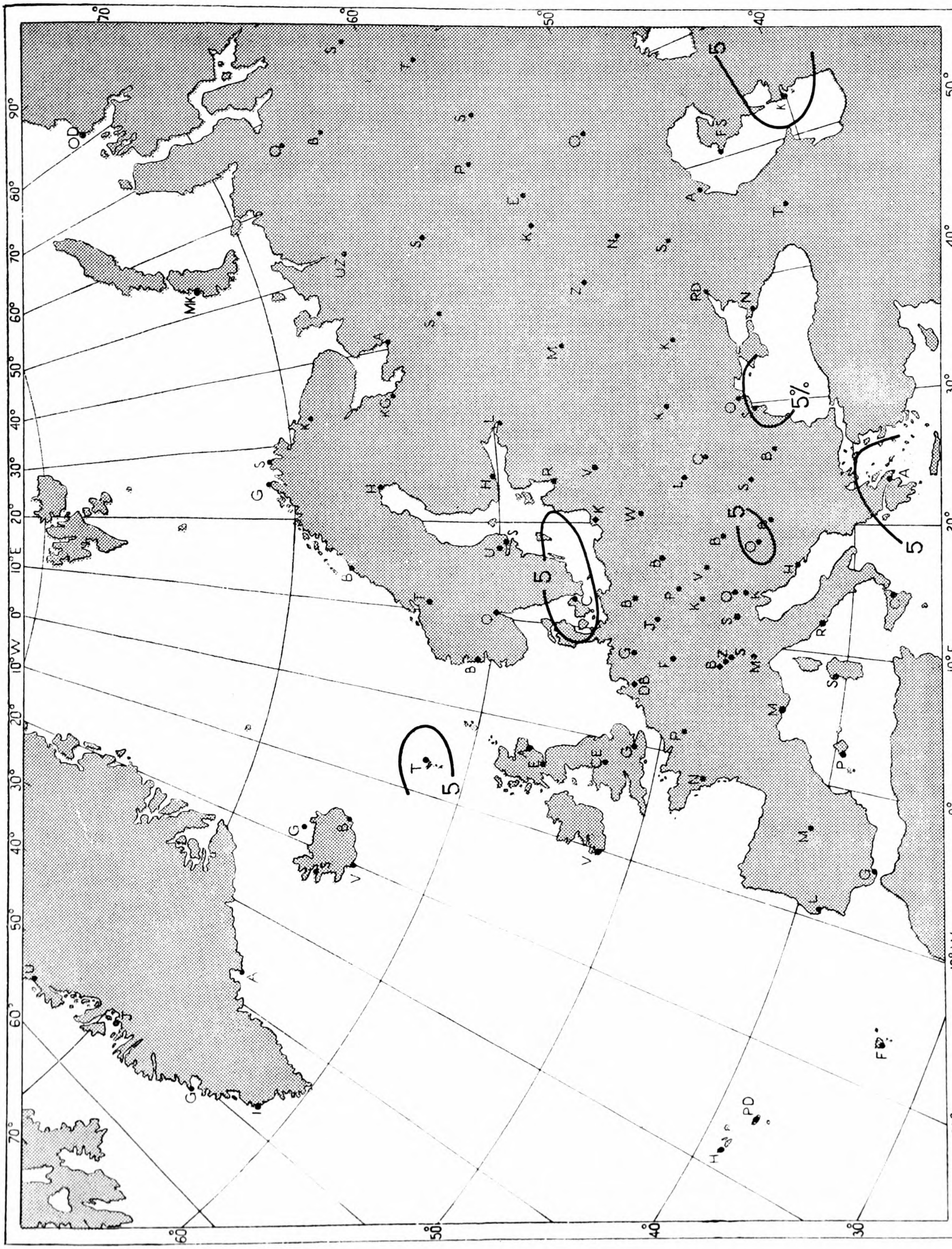

Figure 15. Chart showing the strength of the evidence of association between the temperature anomalies in December and February in Europe and the eastern Atlantic. For further description see note on page 14.

Appendix

The actual values of chi-squared (for 3 × 3 tables) which exceed the 2 per cent level for all stations in Table I are shown below. Values exceeding the 0·1 per cent level are in italics. In each case the mean temperature for the month in question is related to that of the month before.

January

Station	Chi-squared
Edinburgh	12·14
Central England	18·09
Copenhagen	14·14
Greenwich	14·66
Horta	16·65
Helsinki	*19·06*
Bodo	12·53
De Bilt	12·54
Kola	14·27
Stockholm	*24·69*
Jakobshavn	14·28
Orenburg	16·15
Trondheim	14·27

February

Station	Chi-squared
Bergen	13·48
Central England	17·11
Copenhagen	*30·87*
Breslau	13·29
Konigsberg	15·41
Funchal	12·76
Sassari	13·82
Milan	13·23
Osijek	*21·25*
De Bilt	11·99
Klagenfurt	12·62
Budapest	17·29
Stockholm	*26·60*
Upernavik	14·29
Jakobshavn	12·67
Godthaab	14·18
Krasnovodsk	13·21

March

Station	Chi-squared
Bergen	*25·51*
Aberdeen	13·90
Edinburgh	*25·22*
Palma	12·18
Gibraltar	11·71
Central England	*35·19*
Vilna	*22·36*
Copenhagen	*48·46*
Prague	16·59
Greenwich	15·61
Breslau	*22·08*
Berlin	12·99
Konigsberg	*22·19*
Helsinki	*31·86*
Bodo	16·62
Uppsala	*31·48*
Archangel	12·88
Shenkursk	16·27
Frankfurt	11·95
Sassari	15·12
Milan	*18·93*
Haparanda	*21·25*
Jena	*20·12*
Kremsmunster	15·16
De Bilt	*32·63*
Oslo	*29·49*
Zurich	15·49
Sonnblick	17·03
Marseilles	13·26
Budapest	13·64
Warsaw	13·68
Kola	15·30
Stockholm	*49·32*
Ivigtut	13·57
Godthaab	15·47
Astrakhan	15·19
Trondheim	32·96

April

Station	Chi-squared
Gjesvar	11·73
Gibraltar	12·83
Lisbon	11·96
Central England	18·28
Vilna	16·04
Copenhagen	*19·51*
Greenwich	11·70
Helsinki	15·59
Uppsala	15·84
Kiev	12·09
De Bilt	14·74
Oslo	17·35
Rome	15·17
Sletnes	17·82
Sulina	17·10
Elabuga	14·56
Stockholm	18·46
Rostov na Donu	13·06
Syktyvkar	15·26
Zametchino	14·31
Trondheim	*19·16*

May

Station	Chi-squared
Palma	12·94
Gibraltar	*25·35*
Helsinki	16·63
Uppsala	12·17
Haparanda	15·26

June

Station	Chi-squared
Edinburgh	12·42
Gibraltar	17·94
Vilna	11·71
Ponta Delgada	15·05
Basle	12·40
Helsinki	14·41
Haparanda	13·98
Ust Zylma	11·72
Obdorsk	*20·07*
Vestmanno	13·38
Athens	15·11
Godthaab	13·59
Novorossisk	12·60

July

Station	Chi-squared
Bergen	14·11
Edinburgh	12·85
Palma	12·94
Nantes	12·49
Gibraltar	*20·53*
Central England	*25·62*
Copenhagen	*20·33*
Grimsey	*20·24*
Stykkisholm	*19·06*
Horta	11·95
Helsinki	13·24
Oslo	15·01
Vestmanno	12·58
Sulina	*24·37*
Athens	12·66
Stockholm	17·33
Jakobshavn	12·17
Trondheim	*22·01*

August

Station	Chi-squared
Bergen	*21·70*
Thorshavn	*19·78*
Valentia	12·64
Lisbon	12.84
Copenhagen	*44·19*
Greenwich	13·61
Berujsfjord	14·05
Grimsey	18·00
Stykkisholm	11·90
Ponta Delgada	16·90
Horta	*20·47*
Bodo	15·52
Riga	13·27
Paris	12·54
Oslo	*22·84*
Vestmanno	*19·60*
Bucharest	13·48
Athens	12·80
Stockholm	11·95
Godthaab	*23·57*
Tiflis	12·91
Trondheim	*22·56*

September

Station	Chi-squared
Edinburgh	*21·47*
Nantes	*26·06*
Gibraltar	17·38
Central England	*24·53*
Copenhagen	18·19
Greenwich	16·44
Berujsfjord	14·90
Horta	*21·50*
Konigsberg	15·96
Paris	12·80
Jena	12·91
De Bilt	*22·00*
Bucharest	18·41
Warsaw	11·69
Athens	12·45
Stockholm	17·43

October

Station	Chi-squared
Copenhagen	14·72
Prague	12·72
Konigsberg	15·35
Basle	15·46
Funchal	17·11
Archangel	14·48

October—*cont.*

Station	Chi-squared
Paris	12·92
Odessa	12·42
Fort Shevchenko	18·29
Novorossisk	13·77

November

Station	Chi-squared
Funchal	18·02
Milan	11·86
Kremsmunster	11·92
Elabuga	14·44
Kazan	16·51
Angmagssalik	17·35

December

Station	Chi-squared
Berlin	14·13
Helsinki	*21·89*
Haparanda	15·64
Athens	11·74
Stockholm	*22·21*
Rostov na Donu	12·86
Stalingrad	12·03
Upernavik	12·17
Novorossisk	16·97

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