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AIR MINISTRY

METEOROLOGICAL OFFICE

Scientific Paper No. 6

Seasonal Variation of the Sea Surface Temperature in Coastal Waters of the British Isles

by F. E. LUMB, M.Sc.

LONDON: HER MAJESTY'S STATIONERY OFFICE

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The I.C.E.S. charts of mean sea temperature for January and July only have been included in Scientific Paper No.6, but a complete set of twelve individual monthly charts was widely distributed recently within the Meteorological Office. Readers can usefully refer to these, e.g. plates 8 to 12 can be compared with the appropriate monthly charts.

F. E. Lumb
(F. E. Lumb)

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Contents

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SUMMARY

Quite large gradients of sea surface temperature are present round the coasts of the British Isles for much of the year, and the pattern of sea surface isotherms is complex in summer. A study of the temperature gradients and isotherm patterns and an understanding of how they are caused is necessary in order to be able to interpret the sea temperature readings from lightvessels and ships in coastal waters. Also a knowledge of the sea surface temperature distribution in coastal waters can be a valuable aid to local forecasting (for example, coastal fog and low stratus).

TYPICAL WINTER AND SUMMER ISOTHERM PATTERNS

Monthly sea surface temperatures of North Atlantic Ocean[1]* gives a good general picture of the mean monthly sea temperature over the North Sea, the English Channel and the Western Approaches but, as mentioned in the introduction to this publication, the charts are not representative of coastal waters, since few ships' observations are taken close inshore. However, provisional mean charts of sea surface temperature over the North Sea and adjacent waters have been prepared at the Fisheries Laboratory, Lowestoft, and reproduced by the International Council for the Exploration of the Sea (ICES), Charlottenlund, Denmark. A list of the sources of information on which they are based is given at the end of the Bibliography. The scale of the charts and the wealth of data on which they are based, which includes sea surface temperature measurements made at numerous lightvessels and coastal stations, has enabled isotherms to be drawn at 1°C intervals (and at 0·5°C intervals where appropriate) over the whole area of the chart including coastal waters. They show that there are well marked gradients of sea surface temperature round the coasts of the British Isles for most of the year; also that the isotherms of mean sea surface temperature in coastal waters have a basic winter pattern which prevails from November to March, and a basic summer pattern which prevails from May to September. April is a transitional month between the winter and summer states, and is characterized by generally weak sea surface temperature gradients. During September the basic summer pattern weakens rapidly and is replaced during October by a poorly developed winter pattern, so that for much of this period the temperature gradients are again generally weak.

Plates 1 and 2 are the ICES charts for January and July and show the basic winter and summer patterns. In winter the essential features are the warm tongues extending up the Irish Sea and up the English Channel into the southern North Sea. These tongues are more pronounced than those shown in *Monthly sea surface temperatures of North Atlantic Ocean*;[1] also the strong sea temperature gradient between the Isle of Man and the coast of north-west England is not sufficiently emphasized in that publication. In winter strong coastal gradients can be expected anywhere round the coasts, extending out to approximately the 30-fathom line.

* Superscript figures refer to the Bibliography on p. 8.

In summer the situation in the Irish Sea and the English Channel is reversed. Both these regions are now relatively cold and there is a well marked minimum in the North Channel. The strong gradient between the Isle of Man and the coast of north-west England again exists, but is reversed. Another striking feature is the relative coldness of the coastal waters off the east coast from Yarmouth northwards. All these features are more pronounced than the maps of *Monthly sea surface temperatures of North Atlantic Ocean*[1] indicate.

Although not shown in Plates 1 and 2, according to Craig,[2] strong coastal gradients exist also along the west coast of Scotland in winter and summer, but the isotherm pattern is very complex, owing to the irregular nature of the coastline and the large local variations of the depth of water.

Since August 1952, charts of mean sea temperature for each month over the North Sea, the English Channel and the Western Approaches have been prepared by the ICES using data from certain commercial vessels, lightvessels and fishing research ships. A study of these charts shows that the basic winter and summer isotherm patterns are very stable. The main features are still recognizable, even after long spells of abnormal weather conditions, although the coastal gradients are intensified in relatively cold winter months and in relatively warm summer months. The conservative character of the basic patterns can be illustrated by considering two contrasting winter months and two contrasting summer months. Plate 3 shows the isotherms as drawn on the ICES chart for March 1955, a cold month with persistent winds from between north and east following a cold January and February. Plate 4 shows the isotherms as drawn on the ICES chart for March 1957, a very mild month with persistent winds from between south-west and south-east following a predominantly mild January and February. Despite the significant difference in the general level of sea temperature (1°–3°C), the isotherm patterns are broadly similar. The basic winter pattern can be found on both charts, although the coastal gradients along the coasts with off-shore winds (that is, the south and west coasts) are much more pronounced in the cold March of 1955.

Plate 5 shows the isotherms as drawn on the ICES chart for August 1954, the third of a series of dull and cold months with generally disturbed weather, whereas Plate 6 shows the isotherms for August 1955, a warm, sunny month, following a warm, sunny July. (On both these charts, the isotherms drawn near the east coast of England as far south as the Thames Estuary, were based on only a few observations. They have been modified to take into account additional sea temperature readings made at Longstone Lighthouse, Humber, Dowsing and Newarp lightvessels, and by some merchant ships.) Comparing the two charts, we see that the same basic summer patterns appear on both, although the gradients are much stronger in 1955, and the temperature differences between the relatively cold and warm regions correspondingly greater.

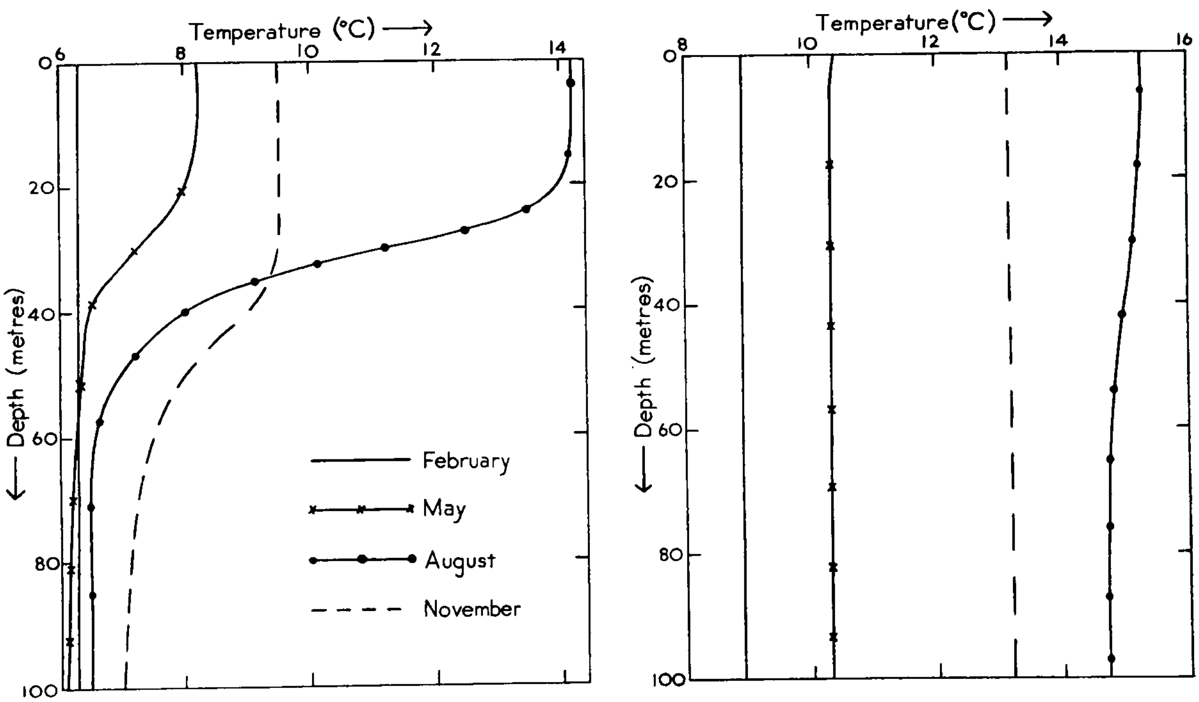
EXPLANATION OF WINTER AND SUMMER ISOTHERM PATTERNS

An explanation of the winter pattern (Plate 1) is straightforward. During the winter the surface layers of the sea are cooled, primarily by radiation and evaporation. Stratification is unstable and vertical mixing is readily effected by wind and waves; this ensures thorough vertical mixing of the sea water, and the resultant vertical temperature distribution is isothermal. Since in coastal waters the mean air–sea temperature difference is greater than over the open sea, and the water is shallower, coastal gradients of sea surface temperature result, which are conspicuous features of the isotherm pattern where the sea bed shelves gradually from the shore.

Over the North Sea, away from the coasts, the gradients of sea surface temperature are generally weak but the normal latitudinal gradient from south to north is reversed, due primarily to the relative shallowness of the waters of the southern North Sea. The general fall of sea surface temperature from north to south is interrupted by a col in the isotherms in the vicinity of 54·5° N 02·5° E, associated with the very shallow waters of the Dogger Bank.

In summer the situation is more complicated. The absorption of solar radiation creates a stable stratification with temperature decreasing downwards. The conversion of such a layer to isothermal (thereby lowering the temperature of the upper part of the layer) requires a strong vertical mixing agency.

Dietrich[3] has pointed out that tidal currents extend right down to the bottom of the sea and, if they are sufficiently strong, will succeed in mixing the whole water column from the bottom to the surface. It is well known that, in the vicinity of the British Isles in summer in regions not affected by strong tidal currents, turbulence produced by wind and waves



(*a*) Middle of North Sea (56° 40′N, 02° 10′E) (*b*) English Channel (49° 49′N, 02° 33′W)

FIGURE 1. Mean temperature profiles

is capable of mixing only a shallow top layer (20–60 metres), in which the vertical temperature-distribution is approximately isothermal and below which is another shallow layer (the thermocline), in which there is a very rapid decrease of temperature with depth. Below the thermocline the water temperature is again almost constant with depth. Dietrich[4] has given diagrams showing the change of mean temperature with depth throughout the year at a point in the middle of the North Sea where the tidal current is weak (maximum speed about one half of a knot) and at a point in the English Channel where the tidal current is strong (maximum speed three knots). From these diagrams vertical profiles of temperature for February, May, August and November have been derived and are shown in Figures 1(*a*) and (*b*). The contrast is striking, the thermocline being well marked in the middle ofthe North Sea but almost non-existent in the English Channel, where the whole water column is isothermal, or very nearly so, throughout the year. If the temperature profile in the central part of the English Channel were similar to that in the middle of the North Sea, the sea surface temperature would be approximately 1°C higher in May than it is, and 4°C higher in August.

Dietrich[5] has also mapped the sea temperature distribution in an east–west vertical cross-section across the North Sea on 15 August 1953. From his cross-section, vertical temperature profiles have been derived for two points in the North Sea at approximately the same latitude, one (ABCD in Figure 2) in the middle of the North Sea (56·5°N 02·7°E) where the tidal current is weak (maximum speed about one half of a knot), and the other (EF in Figure 2) just off Berwick where the tidal current is strong (maximum speed two knots). We see that by mid-August 1953 in the middle of the North Sea, turbulence generated by winds, waves and weak tidal currents had created an isothermal layer only in the top 25 metres, beneath which was a strong thermocline; whereas off Berwick, turbulence due to the strong tidal currents extended throughout the whole layer from the surface to the bottom. The total heat content of the water column at each position was approximately the same, but the water off Berwick had been subjected to much more effective vertical mixing resulting in the sea surface temperature off Berwick being 2°C lower than in the middle of the North Sea in the same latitude.

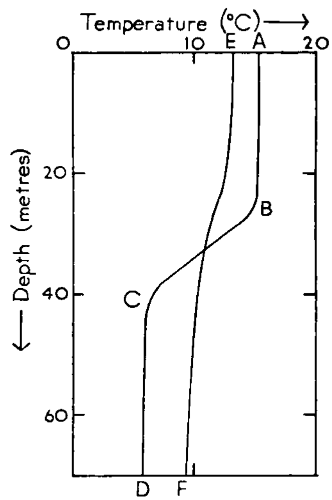


FIGURE 2. Temperature profiles in the North Sea, 15 August 1953 ABCD: 56° 30′N, 02° 42 E; EF: 55° 48′N, 01° 48′W.

It follows that tidal streams play an essential role in determining the sea surface temperature distribution in summer. Using the *Atlas of tides and tidal streams*,[6] a map of isopleths of maximum speed of the tidal currents (at spring tides) has been prepared and is shown in Plate 7. The distribution of these isopleths in relation to the sea depth gives a satisfactory explanation of the summer isotherm patterns. Deep water and strong tidal currents are associated with low surface temperature, for example, the Irish Sea (with a minimum in the North Channel where the deepest coastal waters round the British Isles are found in association with tidal currents whose maximum speed exceeds three knots), between the Orkney and Shetland Isles, off the east coast from Rattray Head southwards, and in the English Channel. Adjacent to the elongated trough in the isotherms off the east coast is a weak ridge due to the influence of the relatively warm waters of the Dogger Bank, where tidal currents are weak and the water is shallow (less than 30 metres).

A strong gradient of sea surface temperature would be expected at the western entrance to the North Channel and in St. George's Channel, where the tidal currents increase in strength rapidly from west to east and from south to north respectively. A strong gradient of sea temperature is in fact shown on Plate 2 in St. George's Channel, but not at the western entrance to the North Channel, probably owing to lack of sufficient data, but some direct evidence of the existence of a strong gradient off northern Ireland will be given later.

The influence of tidal currents is also illustrated by a comparison of Plates 5 and 6. We see that the largest differences of temperature between the two months occur in regions where tidal currents are weak. For example, over the southern North Sea in the vicinity of 55°N 05°E, and north-west of Cornwall, the sea temperature is between 3° and 4°C higher in 1955 than in 1954, whereas in the regions of strong mixing by tidal streams, for example the North Channel, the central part of the English Channel and near Flamborough Head, the difference between the two years is only about 1°C.

During periods of moderate or strong south-west to south-east winds, which drive surface water away from the east coasts, up-welling may be a factor in maintaining the belt of relatively cold surface water off the east coast, but tidal currents are undoubtedly the primary cause, not up-welling, since the cold water off the east coast is a persistent feature of the summer period whatever the prevailing wind direction.

Tidal currents are very variable in space and time, and in some coastal regions, for example off East Anglia, there are complex local variations of depth of water. The sea surface temperature distribution resulting from vertical mixing by tidal currents will therefore be rather complex, particularly during a spell of quiet, sunny weather when adjacent patches of water may differ in temperature by several degrees Celsius. Craig[2] shows the thermogram of a research vessel in the vicinity of the Butt of Lewis on 10 July 1955. There were several almost instantaneous changes of between 2° and 3°C over a total distance of about 25 miles. Nevertheless, after making due allowance for local complexities, the fact remains that the isotherms of Plate 2 show the basic features of the summer isotherm pattern which are confirmed repeatedly by sea temperature readings from ships and lightvessels.

EXAMPLES OF ISOTHERM CHARTS FOR FIVE-DAY PERIODS

With the aid of Plates 1 and 2, over any period of a few days it is possible to draw quasi-synoptic maps of the sea temperature distribution round the coasts of the British Isles, using only sea temperature readings from lightvessels supplemented by reports from a few coasting vessels or selected ships. Plates 8–12 are examples of such maps drawn for the five-day periods 3–7 January, April, June, September and November 1958. Broken lines indicate that the isotherms are based entirely on a comparison with Plates 1 or 2 owing to lack of direct observational evidence.

In Plate 8 we see the typical winter pattern, with well marked warm ridges extending up the Irish Sea and up the English Channel into the southern North Sea. To judge from the temperature of 45°F at Longstone Lighthouse and the temperature of 44°F near Rattray Head in relation to the isotherm pattern of Plate 1 off the east coast of Scotland, the temperature of 40°F in relatively deep water east of Aberdeen is the result of a 5° error, and an adjacent temperature of 46°F on the 9th (shown in brackets) is further evidence that the reading of 40°F was very probably 5°F too low.

Plate 9 is a similar chart for the five-day period of 3–7 April 1958. The basic winter pattern still prevails. The low temperature of 38°F in the North Sea has been accepted since moderate or strong east to south-east winds had prevailed since mid-March. These would drive the colder surface waters of the eastern North Sea towards the north-west with a tendency to cool the western part of the North Sea, particularly the shallower water of the Dogger Bank.

Plate 10 is for the five-day period 3–7 June 1958. The temperatures at the lightvessels refer to 0600 GMT on the 5th. Diurnal variation of temperature has been ignored in drawing the isotherms since there was no prolonged quiet sunny spell of weather during this period. We see that between early April and early June there has been a complete change over to the summer pattern. The belts of relatively low sea surface temperature in the North Channel, the Irish Sea, the English Channel and off the east coasts of England and Scotland are all clearly marked. The strong gradient of temperature from north to south in St. George's Channel is in agreement with what one would expect from the chart of tidal currents. The two temperature readings of 55° and 49°F just north of Northern Ireland were taken by Ocean Weather Ship *Weather Recorder* on 2 June and, although just outside the chosen five-day period, have been included to demonstrate the existence of a strong temperature gradient off Northern Ireland which is probably a persistent feature of the temperature distribution during the summer months although not shown in Plate 2. The sea temperature thermogram for the voyage of *Weather Recorder* from 56·2°N 09·6°W to the Clyde is shown in Figure 3. The cold water of the North Channel is immediately apparent. The temperature fell rapidly between 8° and 7°W and then rose sharply on entering the Firth of Clyde.

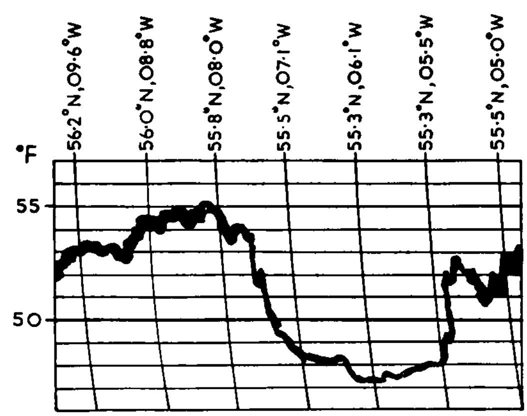


FIGURE 3. Sea temperature thermogram from *O.W.S. Weather Recorder* on 2 June 1958

Plate 11 refers to the period 3–7 September 1958. We again find the basic summer pattern. The value of 62°F at 52°N in St. George's Channel has been accepted, since this was a period of moderate southerly winds. Warm surface water would be advected northwards in this region where there is a strong temperature gradient from south to north and, at least in patches, could temporarily escape mixing by tidal currents. The resulting isotherm pattern in St. George's Channel would probably be more complicated than that shown in Plate 11.

Near Ushant the adjacent temperatures of 59° and 65°F are difficult to reconcile. The value of 59°F has been accepted since this is a region of relatively cold water. Nevertheless, with south-easterly winds prevailing during the period, the reading of 65°F may well be correct, representing a patch of warm coastal water which has temporarily escaped vertical mixing by tidal currents, but it is impracticable to show small variations of this nature by means of isotherms. The reading of 56°F in the southern North Sea has been rejected, since its position is outside the east coast belt of strong tidal currents. The correct reading was probably 61°F (a 5° error).

Plate 12 refers to the period 3–7 November 1958. We see that the basic features of the winter pattern are again established.

SEA TEMPERATURE READINGS FROM LIGHTVESSELS

Plate 13 shows the positions (with names and index numbers) of the various British lightvessels (and Longstone Lighthouse) which make regular observations of sea surface temperature for synoptic purposes.

It is evident from Plates 1 and 2 that sea surface temperature reports from these stations must be used with caution. In winter the east coast lightvessels are not, in general, representative of the western North Sea. However, a good approximation to the temperature of the warm tongue which penetrates into the southern North Sea is given by the Galloper lightvessel (699). Longstone Lighthouse gives a good approximation to the relatively high sea surface temperature in the western North Sea east of Scotland and north-east England.

The Bar and Morecambe Bay lightvessels are not representative of the deep waters of the Irish Sea, but the Skulmartin lightvessel is very well situated to give a good estimate of the temperature of the North Channel and the deeper waters of the Irish Sea.

In summer, temperatures from ships in the North Sea will not usually be representative of the relatively cold water off the east coasts north of Yarmouth. In the absence of ships' reports close inshore, Longstone Lighthouse and the Humber (398), Dowsing (399) and Newarp (498) lightvessels will give a good indication of the temperature of the cold water.

Sea temperatures from the Seven Stones, Shambles and Royal Sovereign lightvessels and from ships at the entrance to the English Channel should not be taken as representative of the temperature of the relatively cold belt of water which extends from Ushant to the Strait of Dover. It is important to watch for ships' temperatures from within this zone.

CONCLUSION

The magnitude and horizontal extent of the coastal gradients of sea temperature throughout most of the year, and the existence of local areas of relatively cold water in summer, are thermal characteristics of the coastal waters of the British Isles which must play an important part in determining local peculiarities of the weather, particularly near the coasts. A regular series of quasi-synoptic charts, of which examples are given in Plates 8–12, might prove to be a useful aid to local forecasting. Using reports from lightvessels and from ships collected over a few days, such charts can readily be drawn, bearing in mind the basic winter and summer isotherm patterns.

ACKNOWLEDGMENTS

I am indebted to Dr. J. N. Carruthers of the National Institute of Oceanography for his very helpful comments and for drawing my attention to some relevant work by the oceanographer Dietrich, and also to the Director of the International Council for the Exploration of the Sea for permission to reproduce Plates 1, 2, 3, 4, 5 and 6.

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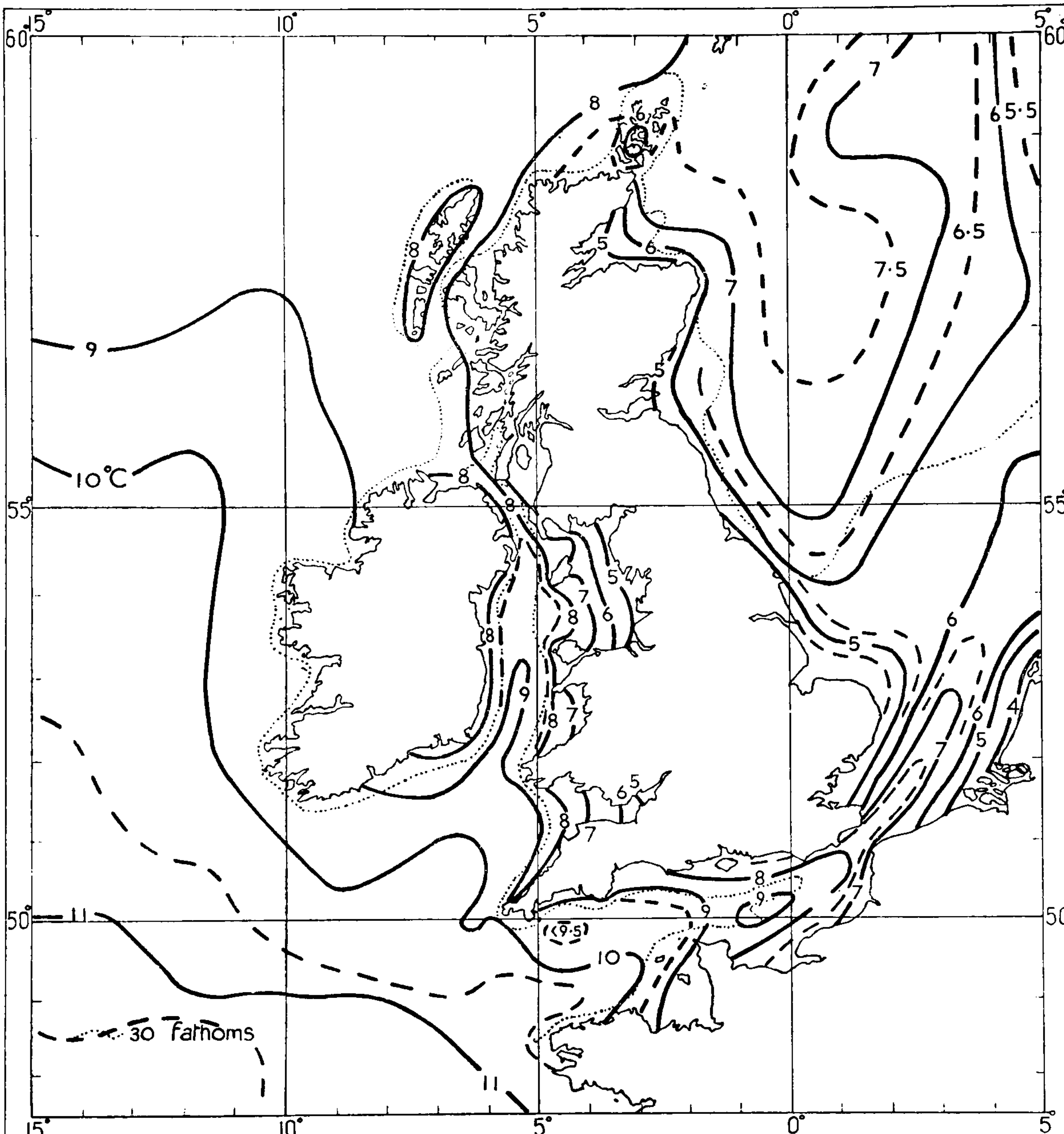

PLATE 1. Mean sea surface isotherms for January

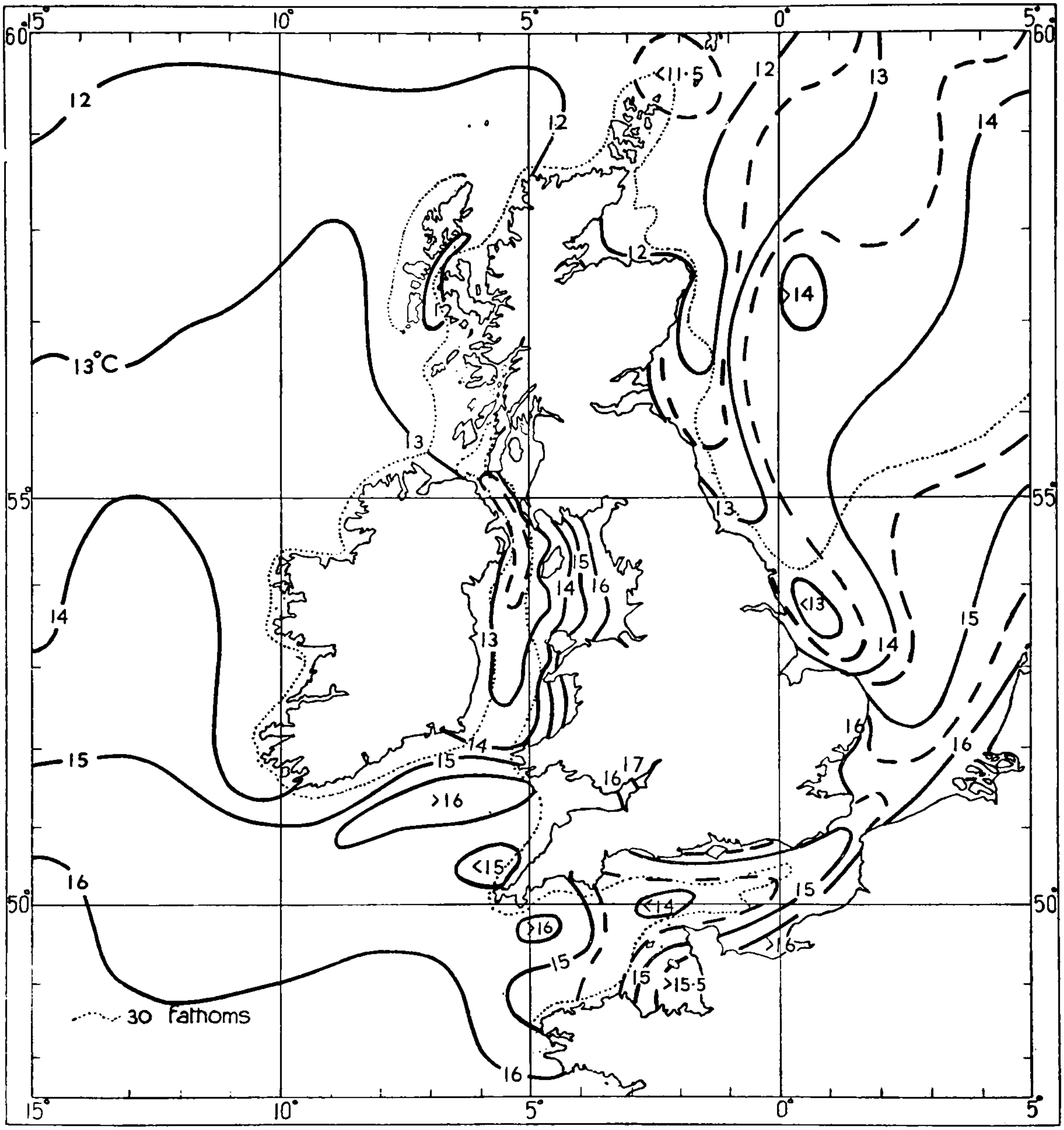

PLATE 2. Mean sea surface isotherms for July

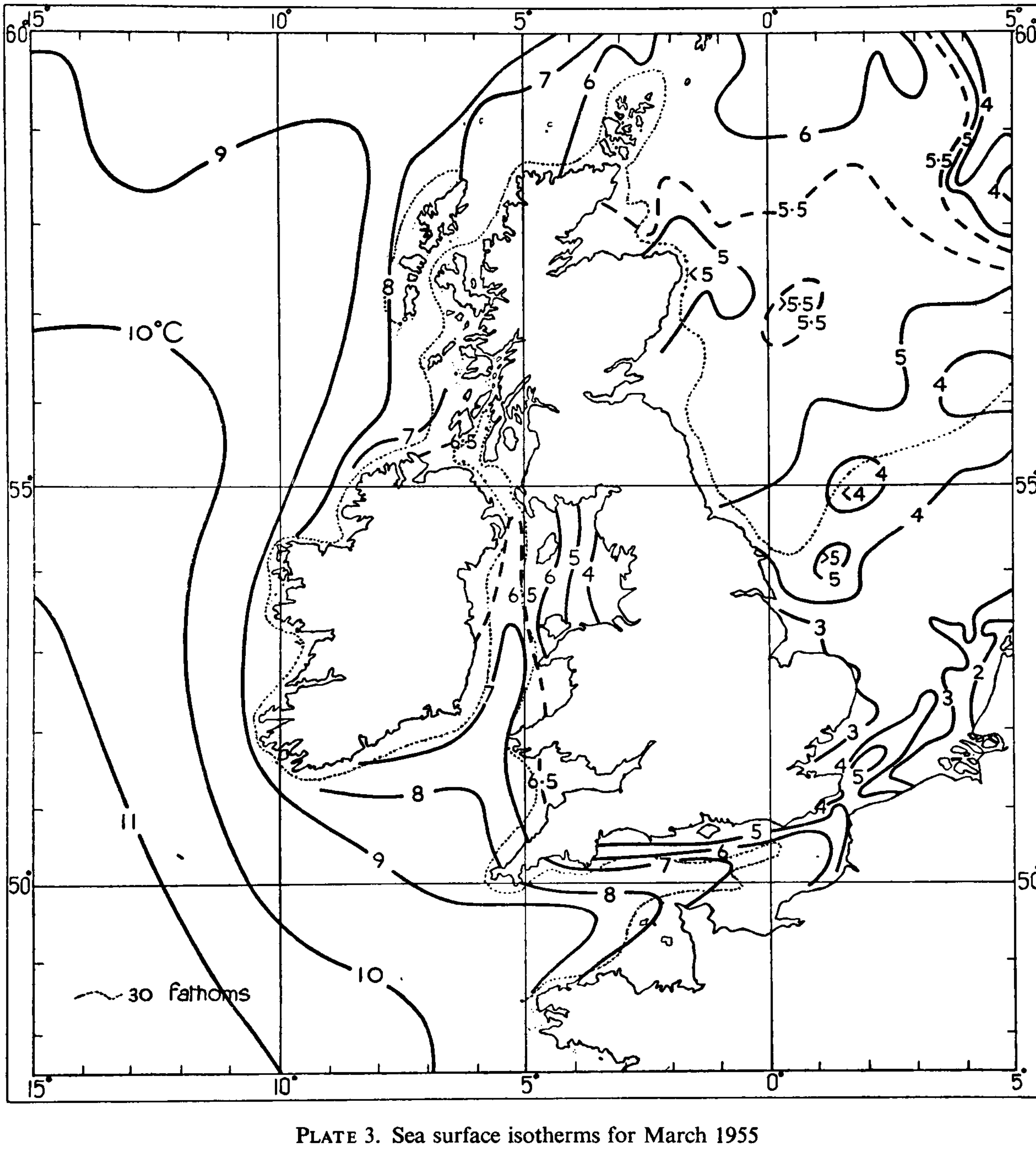

PLATE 3. Sea surface isotherms for March 1955

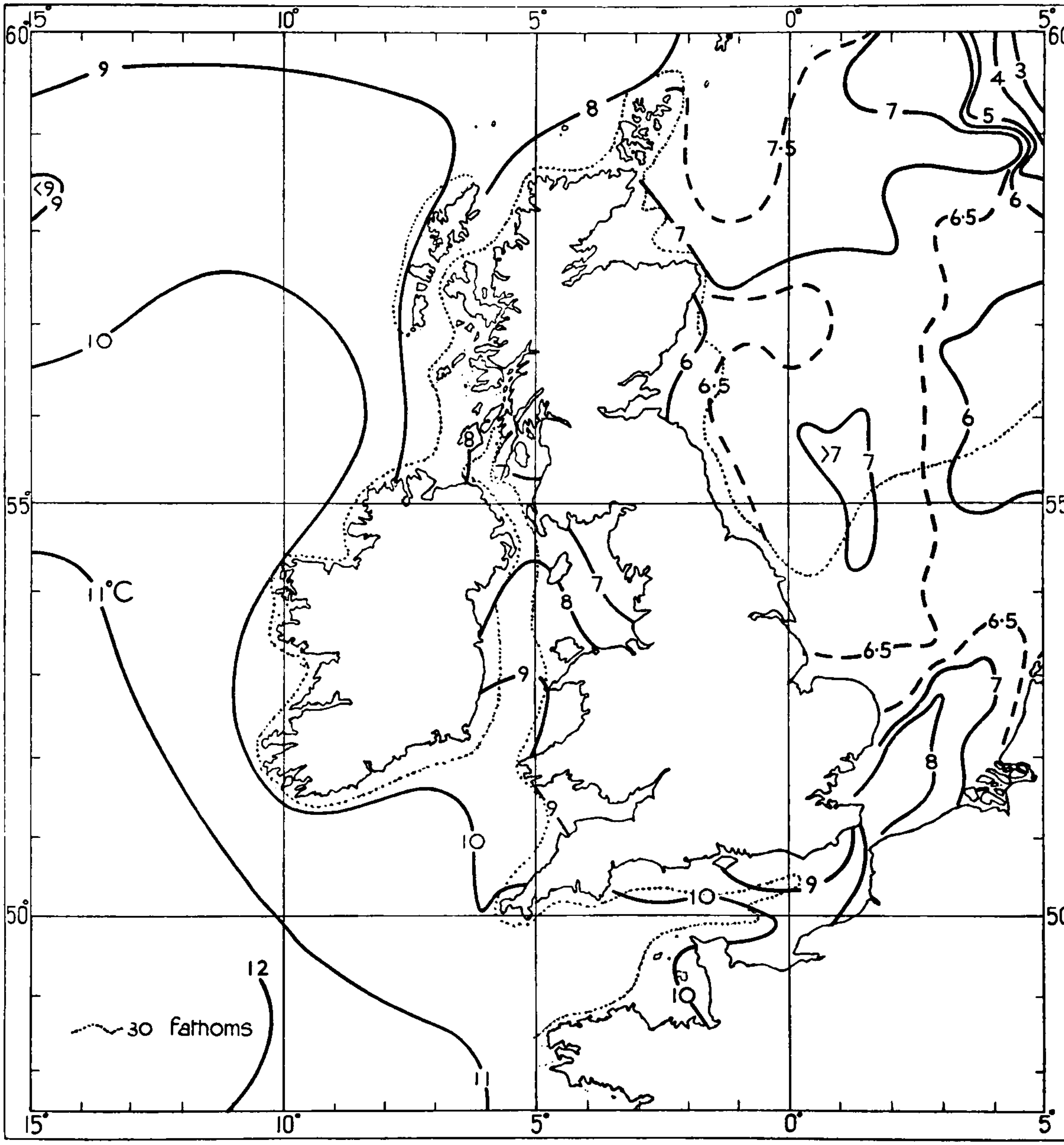

Plate 4. Sea surface isotherms for March 1957

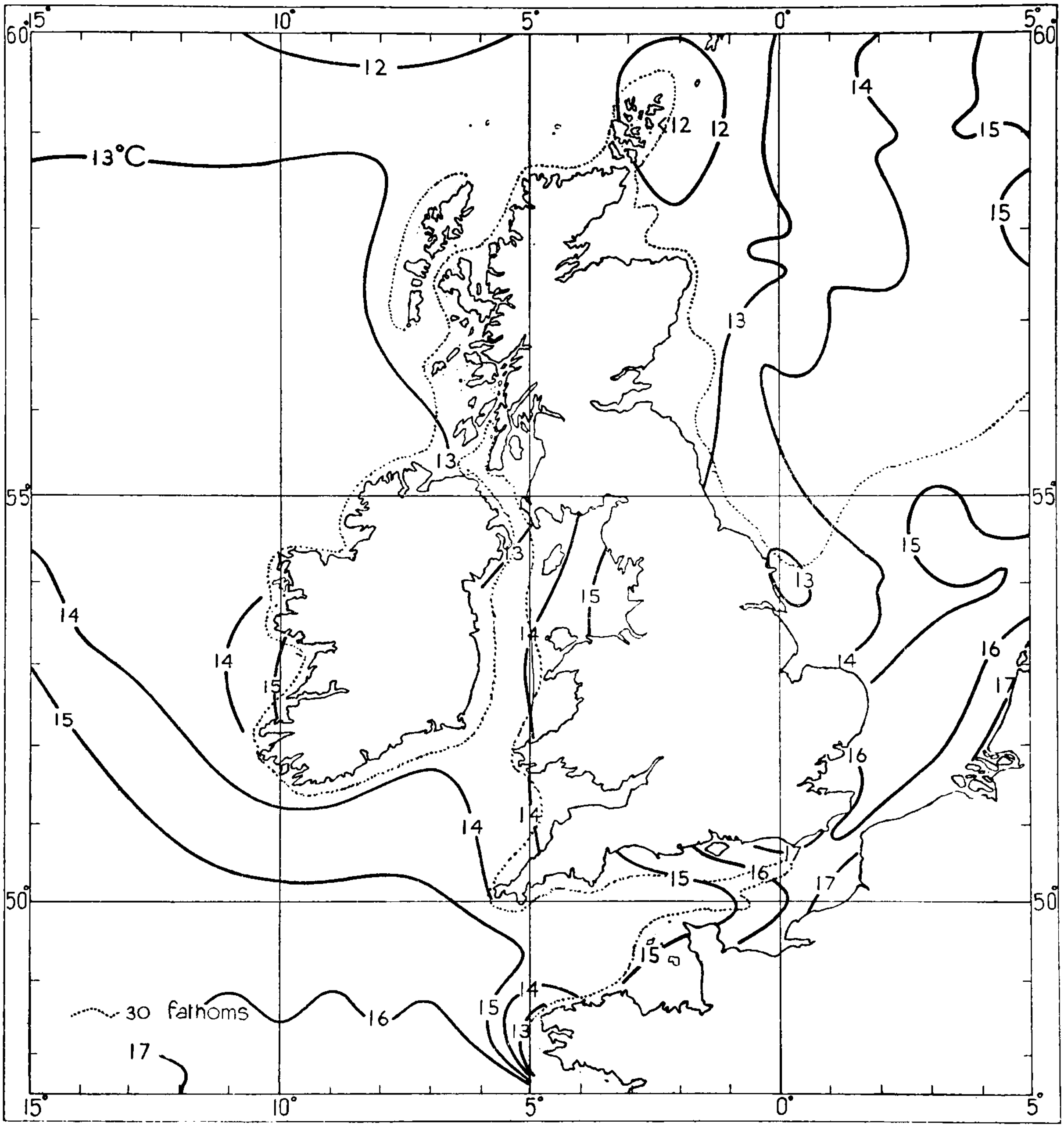

Plate 5. Sea surface isotherms for August 1954

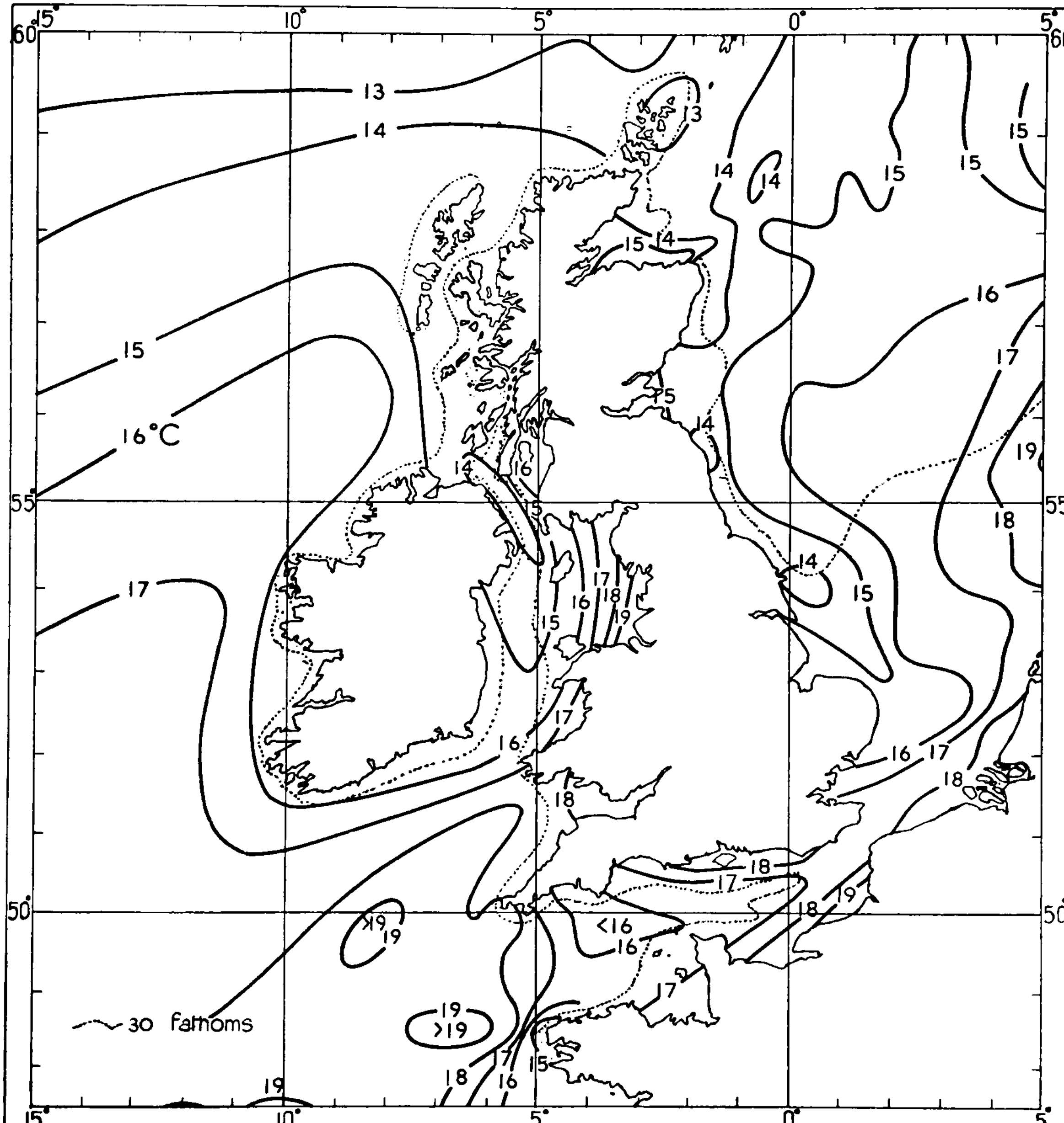

PLATE 6. Sea surface isotherms for August 1955

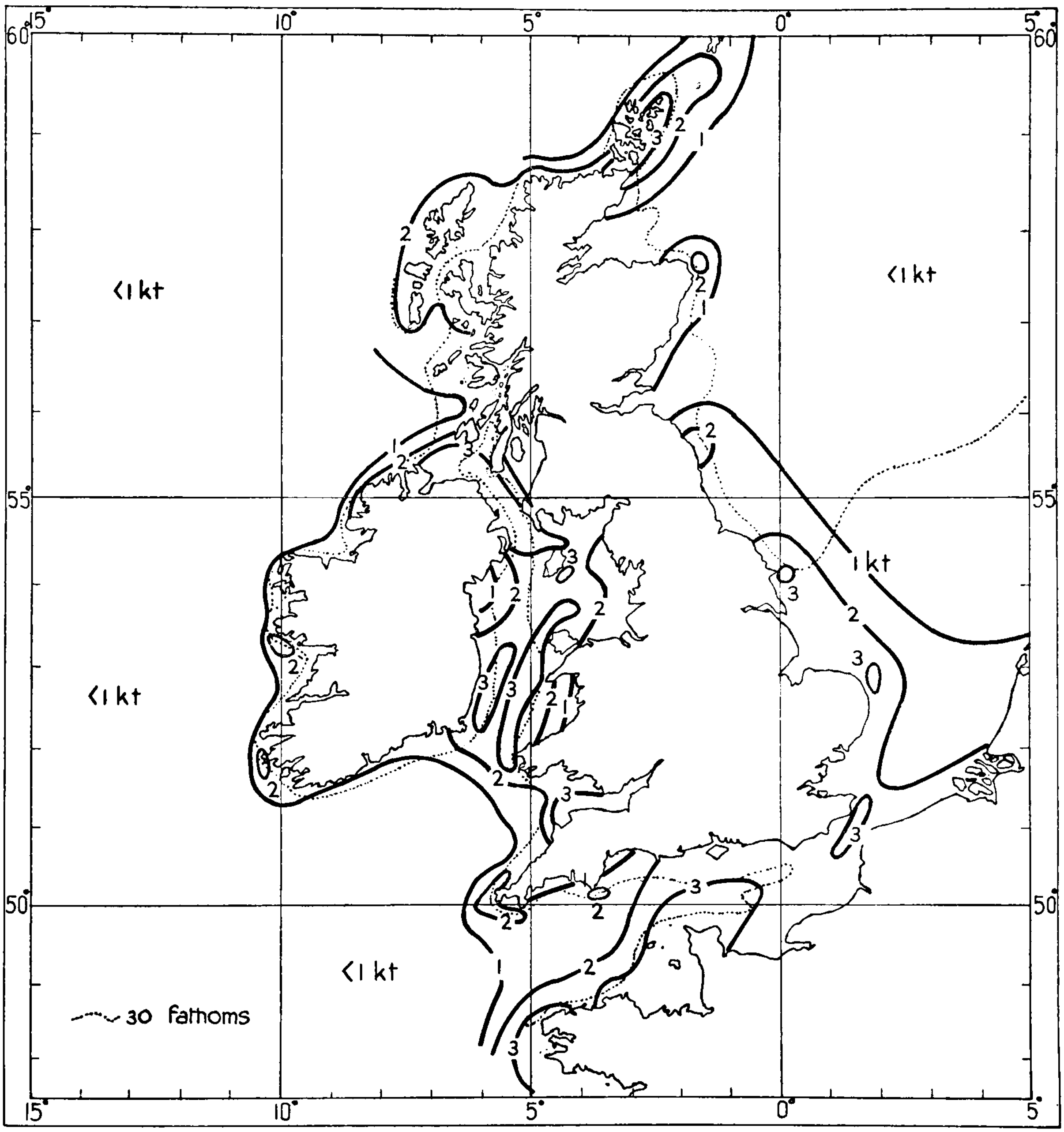

PLATE 7. Isopleths of maximum speed of tidal streams

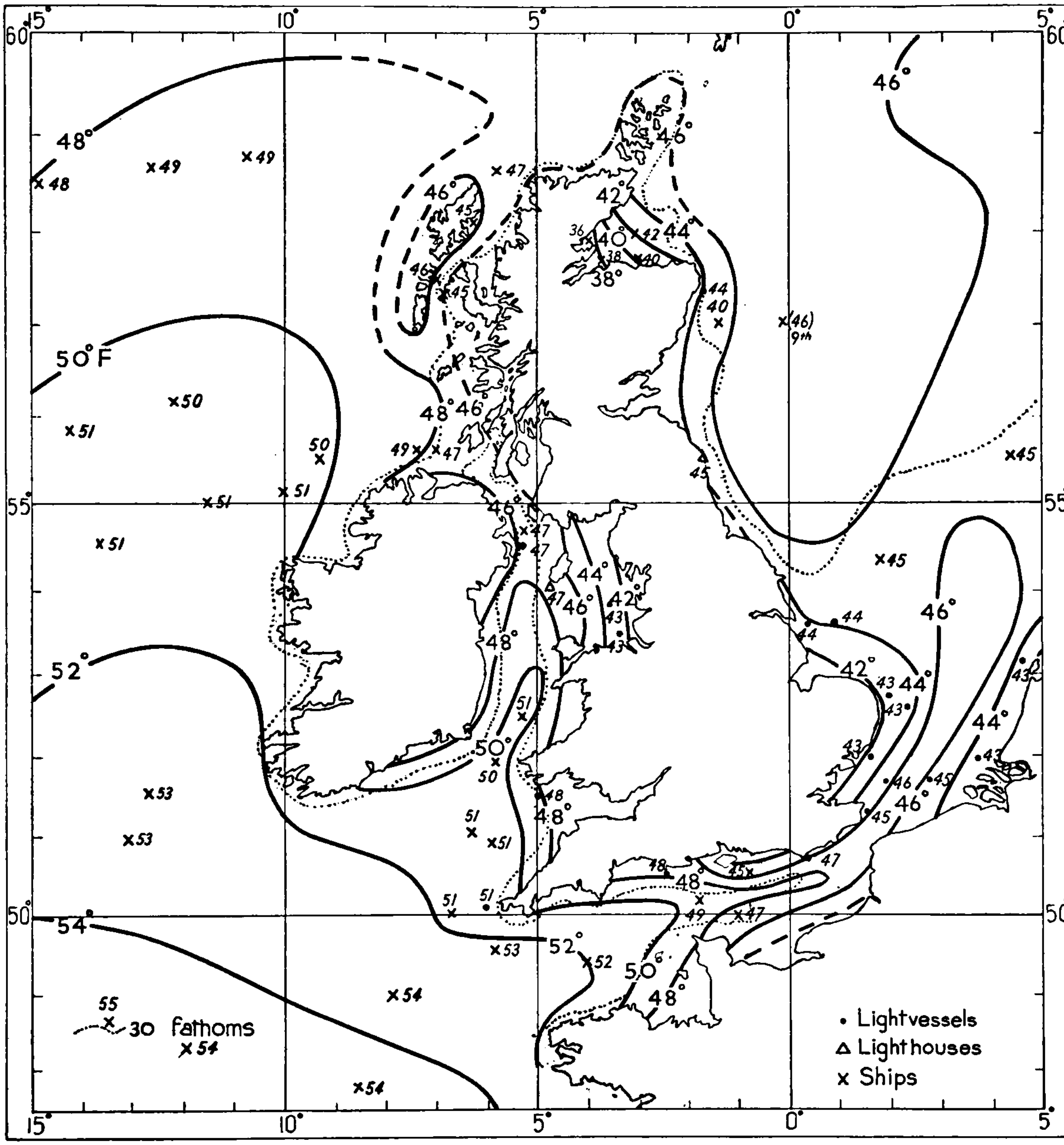

PLATE 8. Sea surface isotherms, 3–7 January 1958

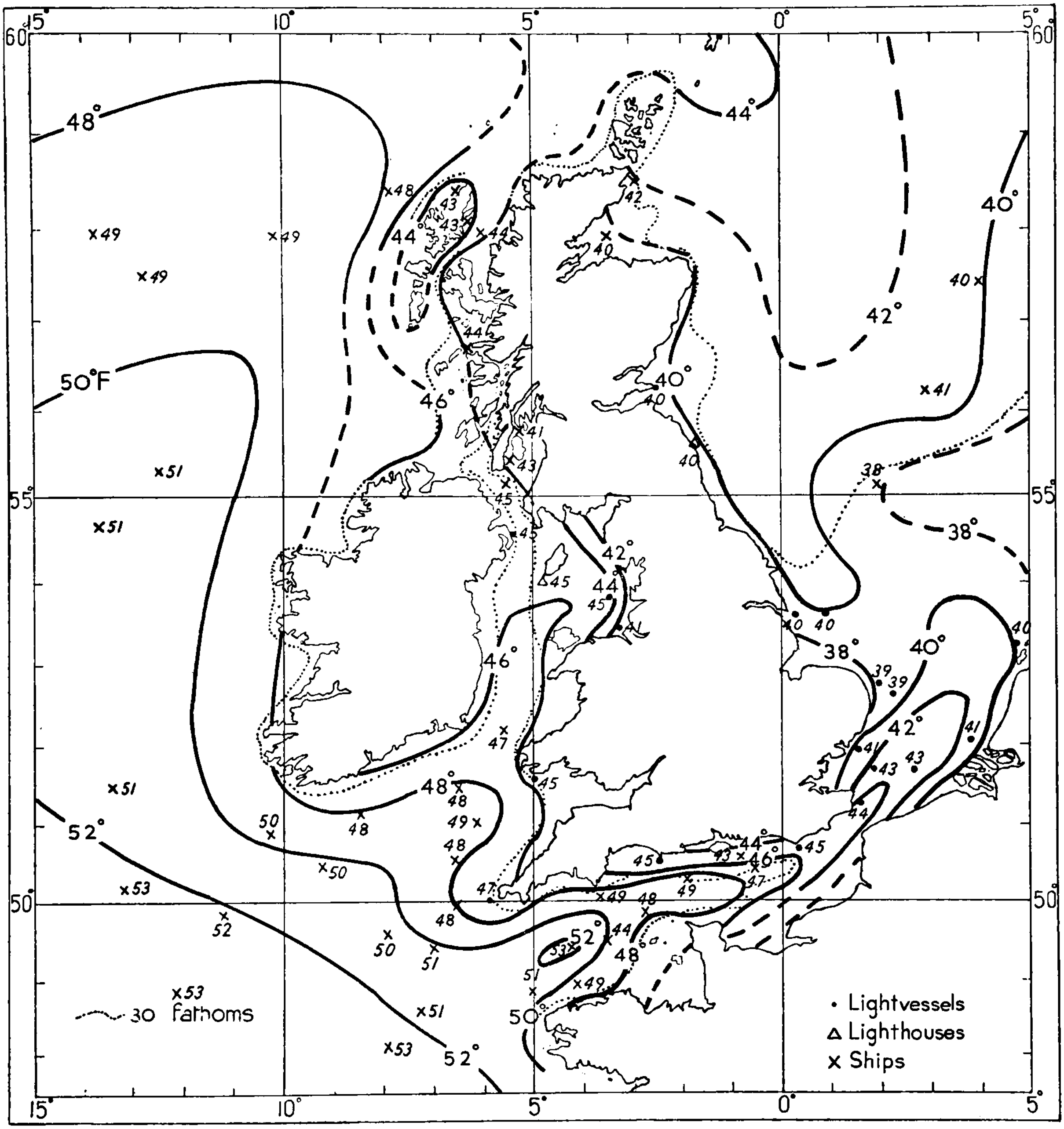

PLATE 9. Sea surface isotherms, 3–7 April 1958

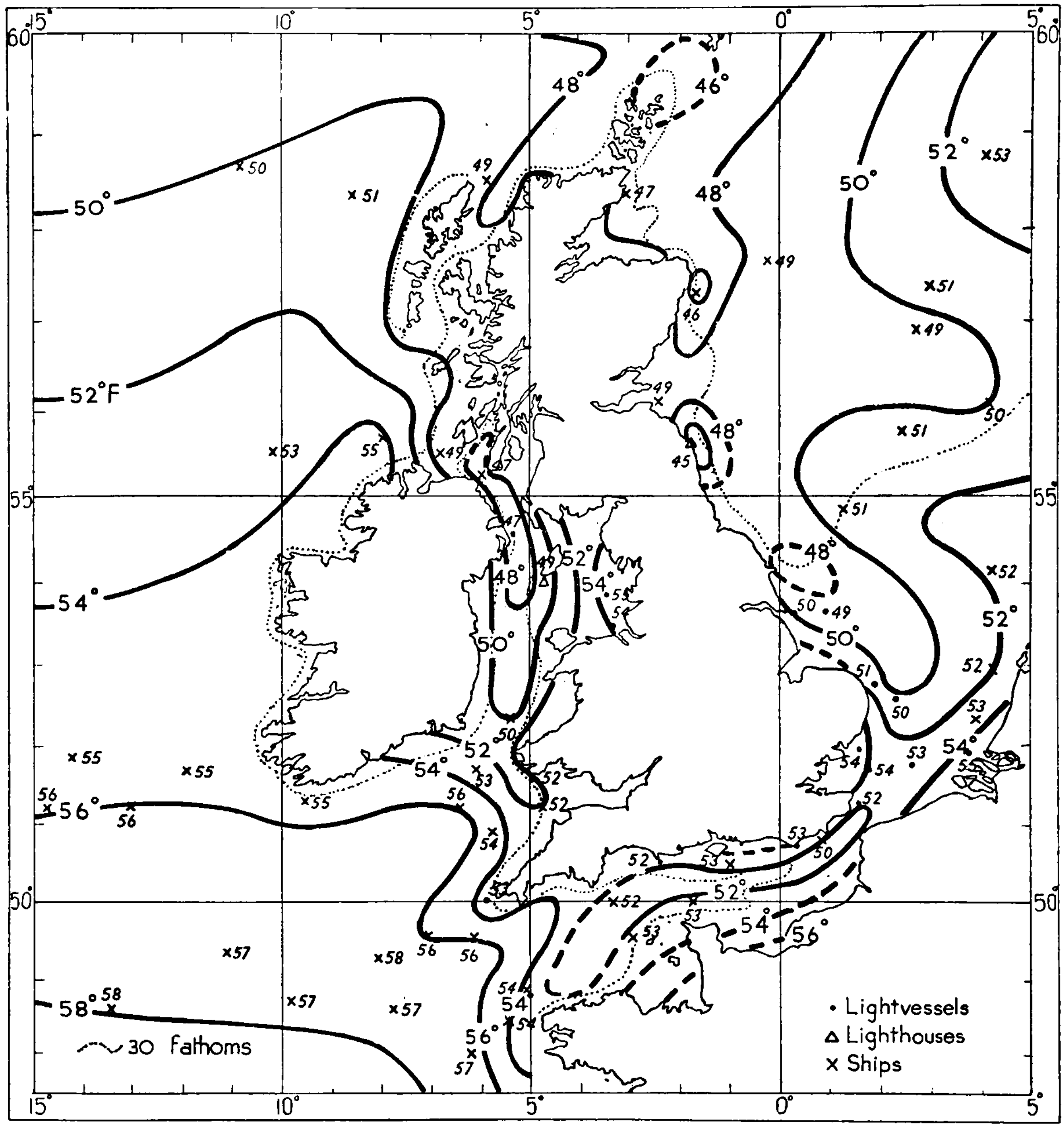

PLATE 10. Sea surface isotherms, 3–7 June 1958

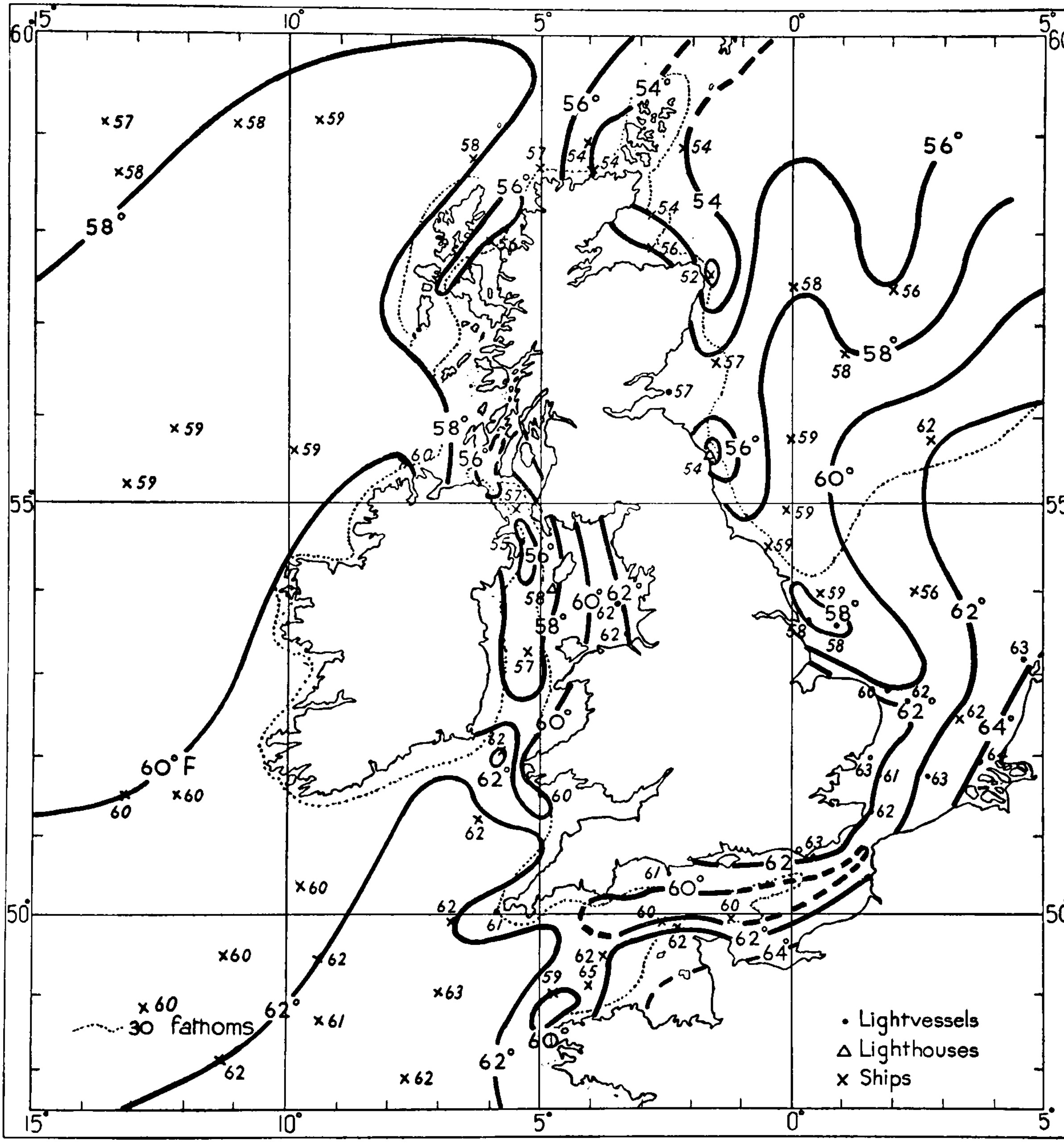

PLATE 11. Sea surface isotherms, 3–7 September 1958

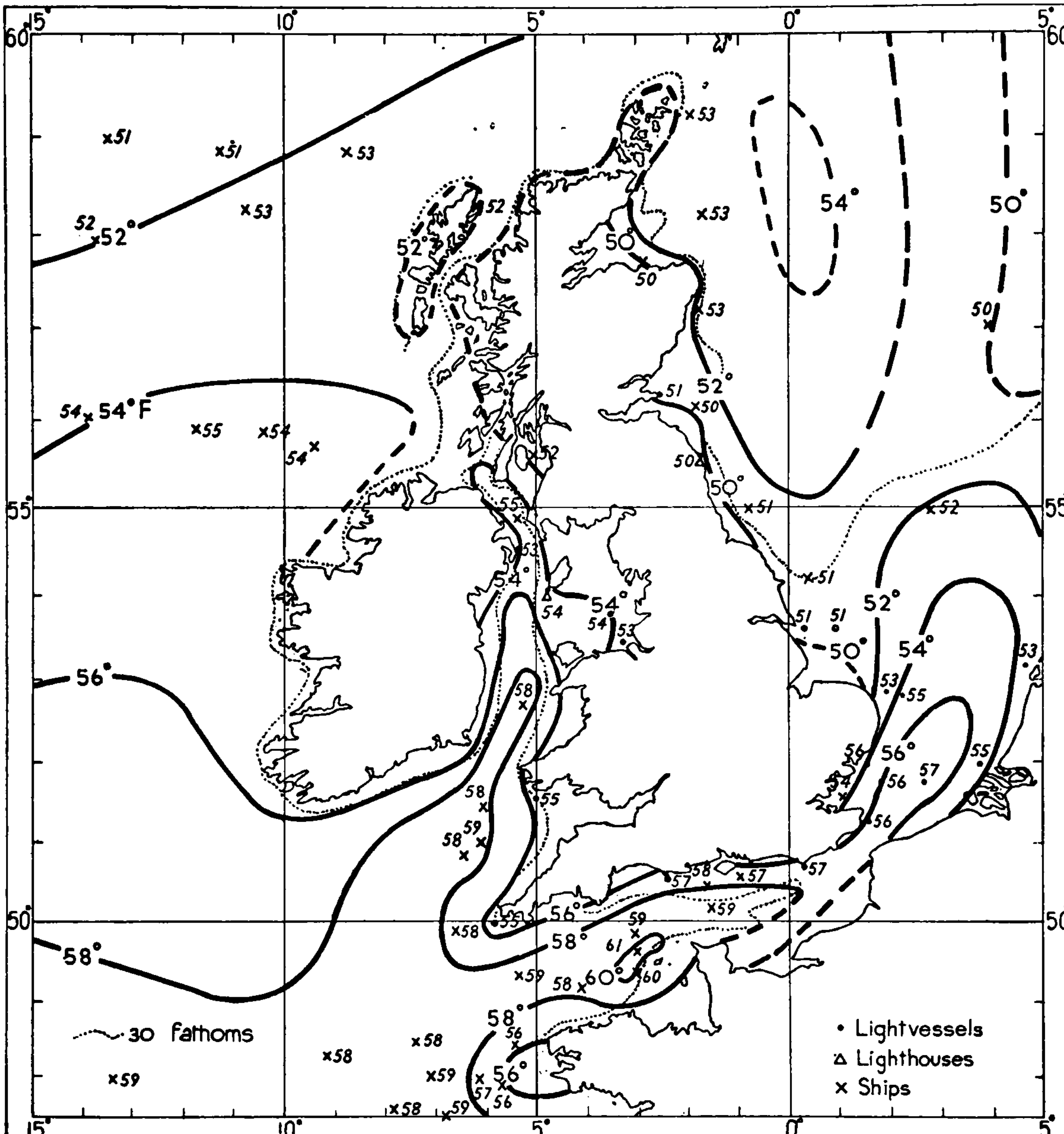

PLATE 12. Sea surface isotherms, 3–7 November 1958

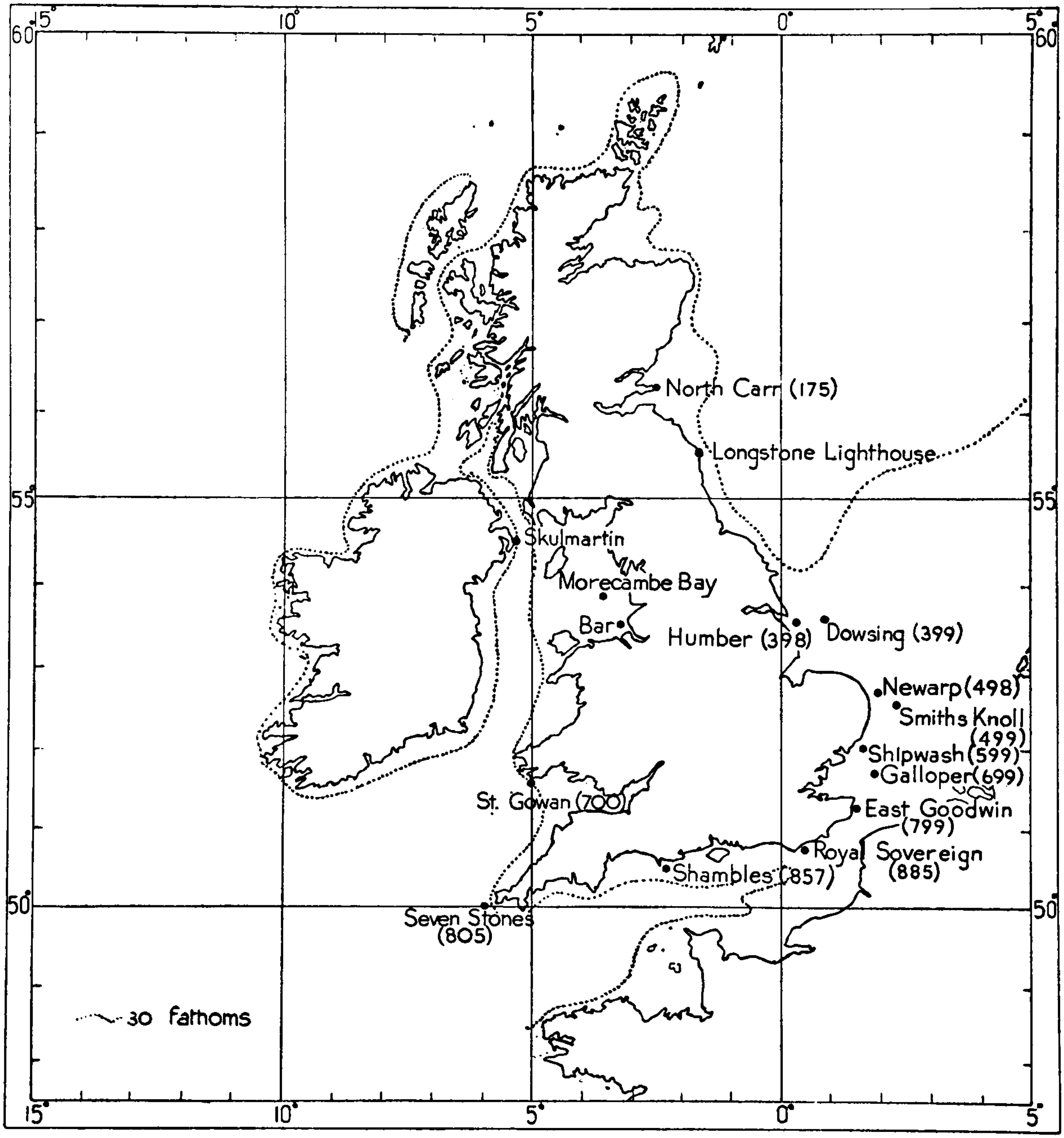

PLATE 13. British lightvessels which report sea temperatures for synoptic purposes

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