SURFACE TEMPERATURE OBSERVATIONS BETWEEN HULL AND HAMBURG, 1877-1883,

BY

D'ARCY WENTWORTH THOMPSON.

CONTENTS.

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By the kindness of Dr. W. N. Shaw, F.R.S., and Captain Campbell-Hepworth, C.B., the Director and Marine Superintendent of the Meteorological Office, we have had an opportunity of examining a valuable series of log-books kept by Captain W. Barron, of the Steamships *Sultan* and *Empress*, on the route from Hull to Hamburg between the dates of October, 1876, and October, 1883.

Besides valuable meteorological observations of various kinds as to wind and weather, height of barometer, air-temperature by wet and dry bulb, etc., these log-books also contain regular observations of the surface temperature of the sea ; and they give us this information for a longer consecutive period than any other observations to which we have had access, save from certain Lightships and other stations at or near the shore.

The sea-temperatures are given in degrees Fahrenheit, read to degrees and half degrees, and as a rule from 8 to 10 observations are recorded, at intervals of four hours, for each passage between the two ports. The passage was made once a week with few interruptions. The position of the ship is not recorded in latitude and longitude, but merely by course and distance in each four hours' watch, and it is therefore only possible or feasible to ascertain the points at which the temperature observations were made by a rough and approximate method. What we have done is as follows. Taking for each voyage the entire distance sailed between the Newsand and the Elbe Outer Lightship, we lay off a corresponding distance upon squared paper, and plot the observed temperatures at points along the line corresponding to the distance made in each watch, that is to say between each pair of observations. The temperature readings are then connected up by a freehand curve. Next, upon the line or ordinate which represents the entire course, the points are found which correspond to the degrees of longitude crossed, namely 1° East to 8° East, and the temperature corresponding to the points where the course crosses the several meridians are read from the interpolated curve. The points at which the course crosses the meridians are, approximately, 1° E., 53° 37′ N. ; 2° E., 53° 42′ N. ; 3° E., 53° 46′ N. ; 4° E., 53° 50′ N. ; 5° E., 53° 54′ N. ; 6° E., 53° 58′ N. ; 7° E., 54° 3′ N. ; 8° E., 54° 7′ N. It is not necessary to point out that this method is a rough one, nor that it is especially liable to error on stormy and lengthened passages. But the errors, inseparable from the method, do not seem to be cumulative, but to be such as cancel one another in the number of observations : and the curve of readings for each voyage comes out, as a general rule, in a clear, even and harmonious manner, indicating steady differences of phenomena along the line of observation. The readings for each month are averaged for each of the eight points where the meridian-lines are crossed, and the average readings are converted from Fahrenheit into Centigrade degrees (Table I). We have next resolved each annual series of monthly averages at each station into a simple harmonic formula, and further the monthly means and the harmonic constants have been averaged for the whole period of seven years. Finally, we have taken for each year the average of the monthly means at *all* the eight points of longitude, and have so obtained a single average estimate of the temperature conditions over this region of the sea for each of the seven years under observation (Table II). In discussing the results, we shall find it convenient to deal with the subject in two parts : firstly the *mean* phenomena, or the average of the results obtained during the seven years for which observations were made, and secondly the particular features presented by each of the seven years.

I. The Mean Phenomena of the Seven Years 1877–1883.

Dealing in the first instance with the monthly averages at the eight stations for the entire series of seven years, and applying to these our elementary harmonic analysis in the manner described in a former volume of our Reports, we obtain, according to the formula $f\ (t) = A_0 + A_1\ \sin(\theta + e_1) + A_2\ \sin(2\theta + e_2)$ etc., average values for (1) the mean temperature, A_0 ; (2) the range, or rather the half range, of temperatures, A_1 ; (3) the *phase* of our sine curve, e_1. From the last of these we may obtain an approximate value for the date of maximum or of minimum, and from the former two we may obtain approximate values for the mean maximum or minimum temperatures of the year, in so far as the fundamental curve is concerned (Tables III, IV).

So far we deal only with the first harmonic, or annual wave, which has its obvious physical interpretation in the course of the seasons, that is to say, in the varying declination of the sun. How far, and in what direction, the actual mean temperatures, as found from the observations, differ from this fundamental sine curve is a matter to be dealt with afterwards.

We now learn, from a study of the results given, that—

(1) The *mean surface temperature* of the sea rises steadily on the line from Hull to the Elbe (Fig. 1), reaching a maximum value rather to the westward of the longitude of

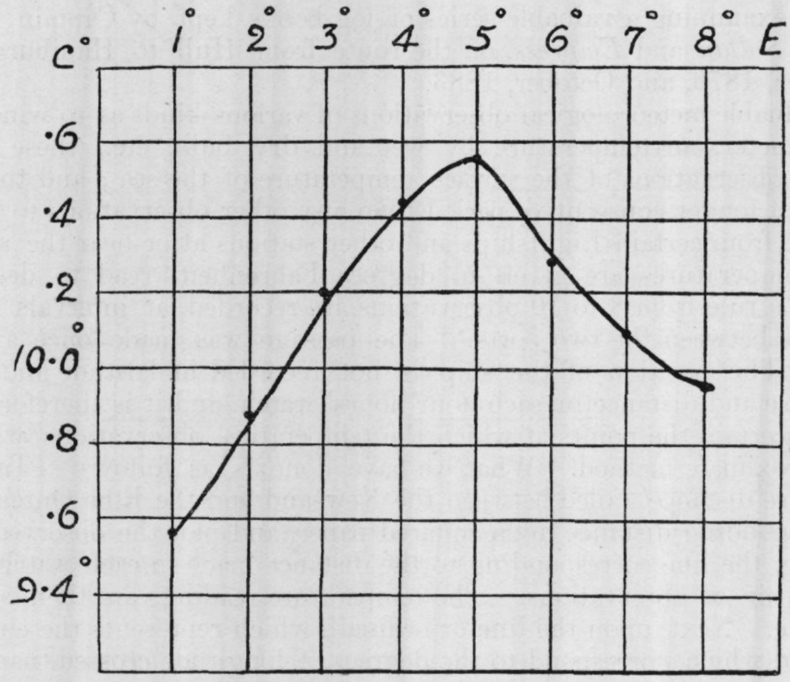

FIG. 1. Mean surface temperature of the sea (1877–1883) along a route from the Humber to the Elbe.

5° East, that is to say due north of the Zuyder Zee or where the Dutch coast bends off to the eastward. From that point towards the mouth of the Elbe, the mean temperature diminishes. At the point named, the mean temperature is nearly 1° Centigrade higher than at our nearest station to the English coast, a little to the north of the Outer Dowsing, and about ·4° C. higher than in 8° East longitude in the neighbourhood of Helgoland (*see* Tables II and III).

This agrees with the results that we have arrived at in recent years, where in our series of temperature observations across the North Sea we have invariably found a higher mean temperature at some intermediate point, and a lower as we pass towards the opposite coasts. In this case, however, it will be seen that the point of highest mean temperature by no means corresponds to the greatest distance from land, nor is it very much further from the continental coast than the more easterly stations along the route, which show a steadily diminishing mean temperature.

If we refer to our observations on the route from Harwich to Hamburg for 1906, we shall see that along that route the point of highest mean temperature is again in the neighbourhood of 5° East, though in 1905 it was apparently somewhat further to the West, in 3° East. Our Leith to Hamburg observations for 1904–1906 show us the highest mean temperature in longitude 6° East. We lack, unfortunately, any series of observations running directly from one of our East Coast ports to the coast of Holland, but nevertheless we have no difficulty in discerning that there is a line of comparatively high temperatures running from the Channel in a north-easterly direction, apparently following in the first place the line of the Dutch coast, but at some distance from it, and afterwards prolonged in a similar direction into the eastern part of the North Sea.

(2) Unlike the mean temperatures, which reach their highest value, as has just been said, at about 5° E., the mean *annual range* of temperature rises greatly, and on the whole steadily, from the Humber to the Elbe (A_1, Table III). The entire range at our first station in 1° E. is about 9·5° C., while in the neighbourhood of Helgoland it is

about 14·7°. The rise is at first somewhat slower, but grows more rapid as we proceed eastward ; it tends to slacken to a slight degree between 5° and 6° E. longitude, but from Borkum to the Elbe the rise is particularly rapid. This phenomenon of an increasing range of temperature as we pass from the insular to the continental coasts is now well-known (Fig. 2*).

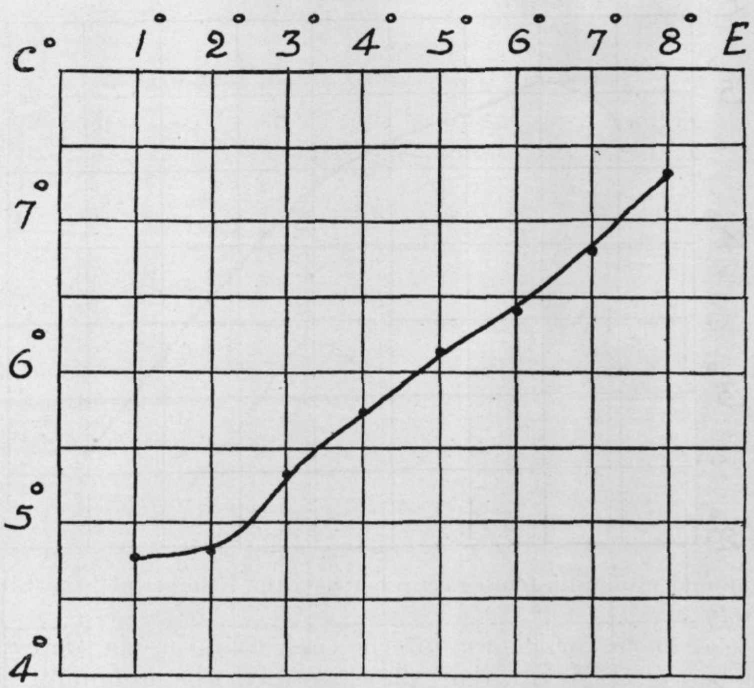

FIG. 2.—Mean half-range of surface temperature (or difference between mean annual temperature and mean maximum or minimum) along a route from the Humber to the Elbe (1877–1883).

(3) The *mean maximum temperature*, as deduced from the mean temperature and the half range, rises gradually as we proceed eastward, but the rise is slow to the eastward of 5° E. (Fig. 3).

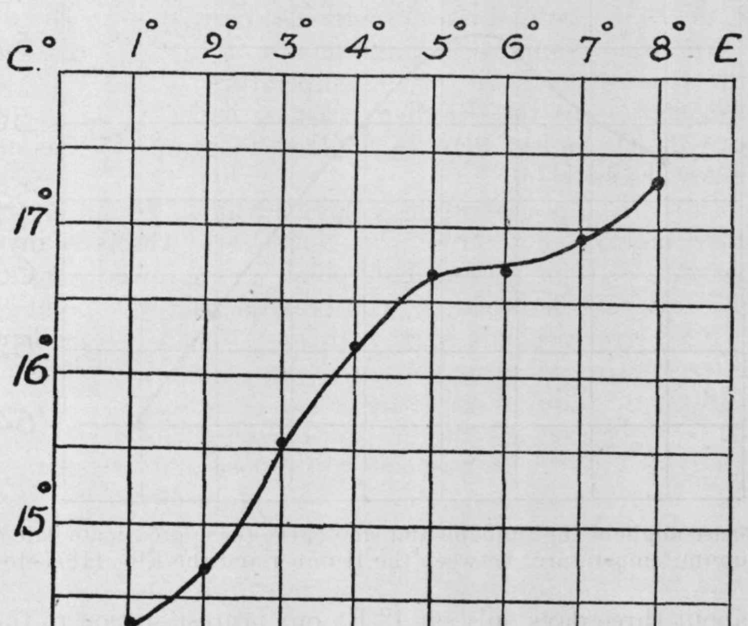

FIG. 3.—Mean annual maximum surface temperature between the Humber and the Elbe (1877–1883).

* After Figs. 2–5 were drawn, a slight inaccuracy was detected in the calculations for 2° E. lat. The figures are stated correctly in Table III, and it will be found that they are such as to remove an apparent slight irregularity of the curves in this region.

(4.) The *mean minimum temperature*, on the other hand, varies little at the stations nearest to the English coast, but falls steadily from 3° E. to the mouth of the Elbe. From 1° E. to 4° E. the mean minimum lies approximately between 4·8° and 5·0° C., but falls to 2·6°, or thereby, in the neighbourhood of Helgoland (Fig. 4).

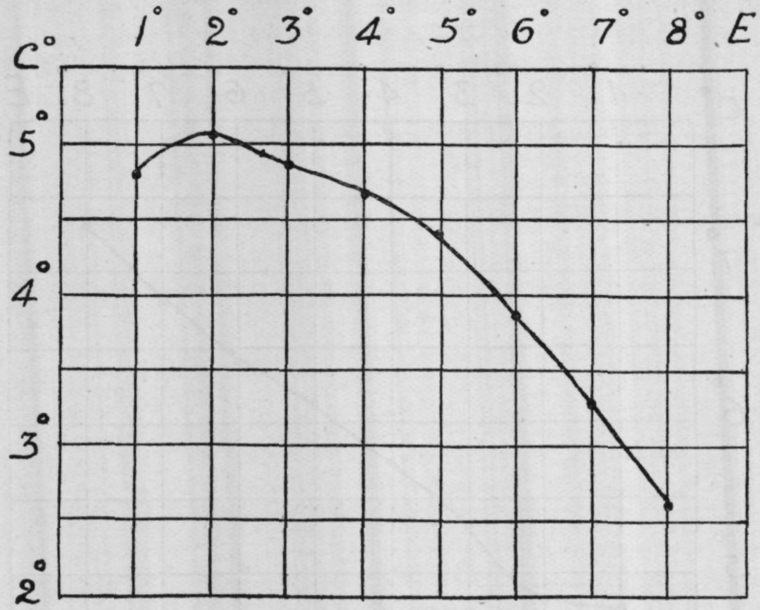

FIG. 4.—Mean annual minimum temperature between the Humber and the Elbe (1877–1883).

(5.) The *phase angle*, which we interpret as giving us the date of minimum and maximum (remembering, however, that these represent the minimum and maximum of the simple sine curve, and must not without correction be assumed as the dates of the actual minimum and maximum) varies in an orderly manner, indicating a mean minimum and maximum at about February 20th and August 20th, from 3° E. to 4° E., with somewhat earlier dates to the westward and eastward of these limits (Fig. 5). The acceleration

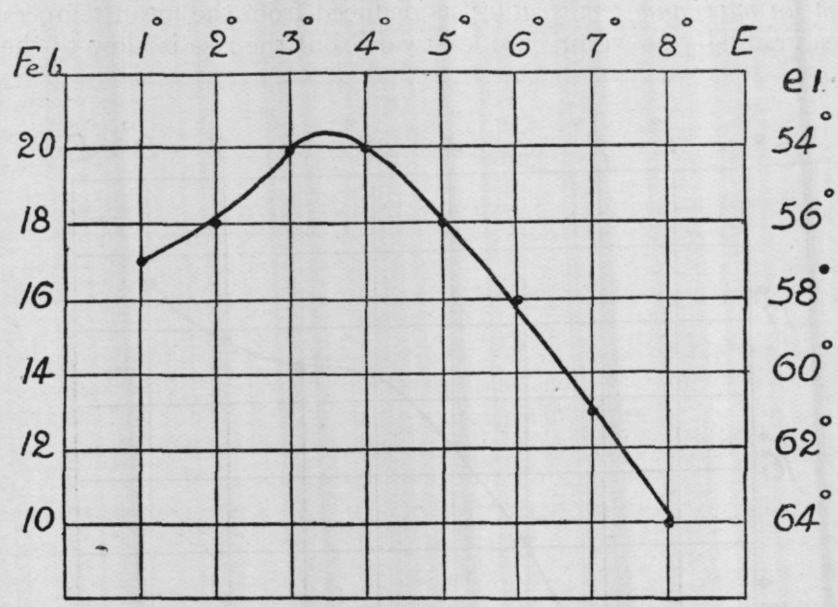

FIG. 5.—Mean phase angle of the fundamental sine-curve (or approximate date of mean annual minimum temperature) between the Humber and the Elbe (1877–1883).

of date is slight, about three days only, at 1° E., our nearest station to the English coast; but it increases rapidly as we approach the German coast, and amounts to an acceleration of about ten days in the neighbourhood of Helgoland. It would be more correct to speak, conversely, of an increasing retardation of seasonal temperature compared with true mid-winter, as we depart from the coast, and an increased retardation likewise in the neighbourhood of the insular coasts as compared with the continental.

(6.) It is interesting to investigate how far, and with what degree of regularity, the mean monthly temperature, as deduced from the simple sine curve, differ from the means of the monthly observations. This difference is to all intents and purposes represented by the factors (A_2, e_2) of the second harmonic, which we have calculated out and set forth in the tables. The higher harmonics are represented by very small and vanishing waves, which we have not recorded, for the double reason that our observations are not accurate enough or frequent enough to indicate them in a satisfactory manner, even if they actually exist, and also because we are not in a position to connect them, if we did prove their existence, with a physical cause. But the case is in so far different with the second sine-factor, or semi-annual wave, in that it always is represented by a factor of considerable amount, and by one which varies on the whole in an orderly way; and we must accordingly presume that it has a definite physical cause, though what that cause is has not yet, so far as I am aware, been determined. While the factor A_1, or half-range of the semi-annual wave, differs considerably in different years, and gives us only a moderately smooth curve for the different stations in each single year (as we might indeed expect from the roughness of our observations, and the small magnitude of the phenomenon), yet for the mean of our seven years it is found to vary very regularly from one end of our route to the other, being fairly constant at about ·5° C. from 1° to 4° E., and then rising rapidly to a maximum of about ·8° C. at 7° E. longitude; at our farthest eastward station near Helgoland it falls slightly (Fig. 6).

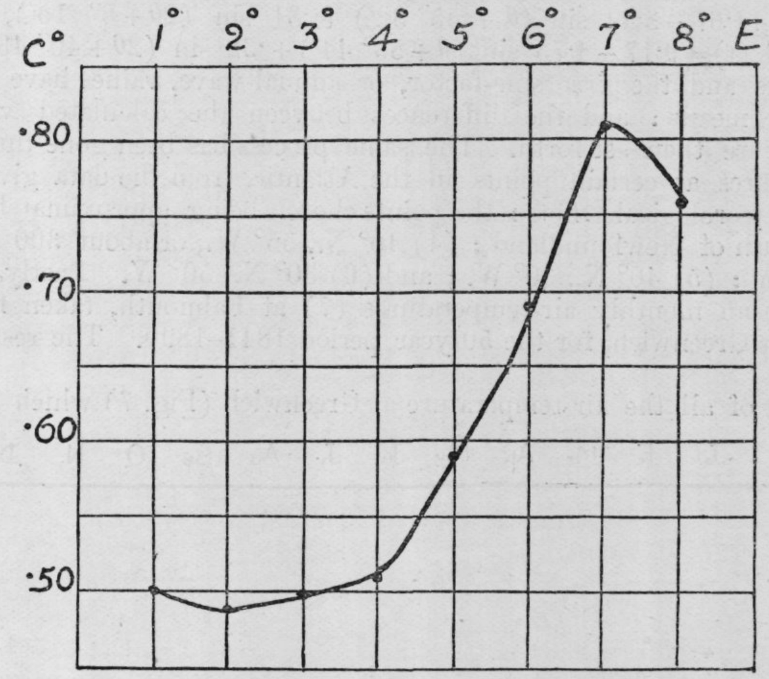

FIG. 6.—Mean value of the factor A_2, or mean of the semi-annual sine-curve of surface temperature, along a route from the Humber to the Elbe (1877–1883).

(7.) It is already well-known that we must take into account this second harmonic in order to obtain a formula which shall give a sufficiently close approximation to the ordinary annual periodic changes of air-temperature. For example, Hann, in his Lehrbuch der Meteorologie (1906), p. 567, shows that, in representing the annual periodic temperatures at Graz by means of a harmonic formula, the inclusion of this second factor, or semi-annual wave, which has there an amplitude of ·70° C., is necessary, and is quite sufficient to give a perfectly adequate approximation to the actual mean daily temperature. It is therefore a phenomenon not peculiar to sea-temperatures, but common to air-temperatures also, at least in temperate zones. For the present, in our case, remembering that the higher harmonics are apparently insignificant, the simplest method of dealing with the phenomenon will be to investigate directly the differences between the monthly means obtained from the observations and the monthly means as taken from the symmetrical annual wave that is given by the first sine curve.

In our former Report we found in dealing with this subject, from the observations made in 1905, that in the case particularly investigated, namely the surface temperatures in the neighbourhood of Helgoland, the observed means were somewhat higher both in summer and winter, and somewhat lower both in autumn and spring, than the sine-formula indicated. The same phenomenon is extremely clear at all points of the line of stations of which we are now treating; and Table V. contains the mean monthly discrepancies for each and all of the eight stations (1° E.—8° E.) during the years

1877–1883. These figures represent a curve with a double maximum in February and in August or September, of which the former is the higher; and a double minimum about April–May and October–November, of which the former is usually the lower. As the maxima of this curve coincide generally with the seasons of minimum and maximum temperature it follows that the temperature never falls quite so low in winter, and rises somewhat higher in summer, than it would do were the whole annual fluctuation governed simply by the fundamental sine curve. We may interpret it in yet other words by saying that the actual temperature rises somewhat too slowly from its minimum and somewhat too quickly towards its maximum, falling likewise too quickly from the maximum and too slowly as it approaches the minimum; that is to say *it fluctuates too quickly when in the neighbourhood of the maximum and too slowly when in the neighbourhood of the minimum.* The phenomenon is *a change in the rate of change* of temperature.

(8). As this phenomenon is of considerable interest, I have enquired a little further into it in several cases. Firstly, I have taken from Mr. H. N. Dickson's paper on 'The Mean Temperature of the Surface Waters of the Sea round the British Coasts'* the values there given for the mean monthly surface-temperature of the sea at (among other stations) (1) Falmouth (1872–85) and (2) the Outer Dowsing (1880–97). These monthly values have been analysed into a sine-curve, the value of which for Falmouth is (in centigrade degrees) $f(t) = 11{\cdot}67 - 3{\cdot}44 \sin(\theta + 55^\circ\, 32') + {\cdot}31 \sin(2\theta + 6^\circ\, 15')$, and for the Outer Dowsing $f(t) = 9{\cdot}17 - 4{\cdot}73 \sin(\theta + 53^\circ\, 44') + {\cdot}32 \sin(2\theta + 40^\circ\, 43')$. From the mean-temperature and the *first* sine-factor, or annual wave, values have been calculated for the monthly means: and the differences between the calculated values and the observed values are then set forth. The same process has been gone through for mean surface-temperatures at certain points in the Atlantic, from the data given in the Pilot Charts of the Meteorological Office: the points chosen being approximately (3) 45° N., 55° W., just south of Newfoundland; (4) 40° N., 55° W., or about 300 miles south of the former station; (5) 40° N., 30° W.; and (6) 30° N., 50° W. Lastly, similar results are given for mean monthly air-temperatures (7) at Falmouth, taken from Dickson's paper, and (8) at Greenwich, for the 50-year period 1841–1890. The results are shown in Table VI.

Taking first of all the air-temperature at Greenwich (Fig. 7) which is based on the

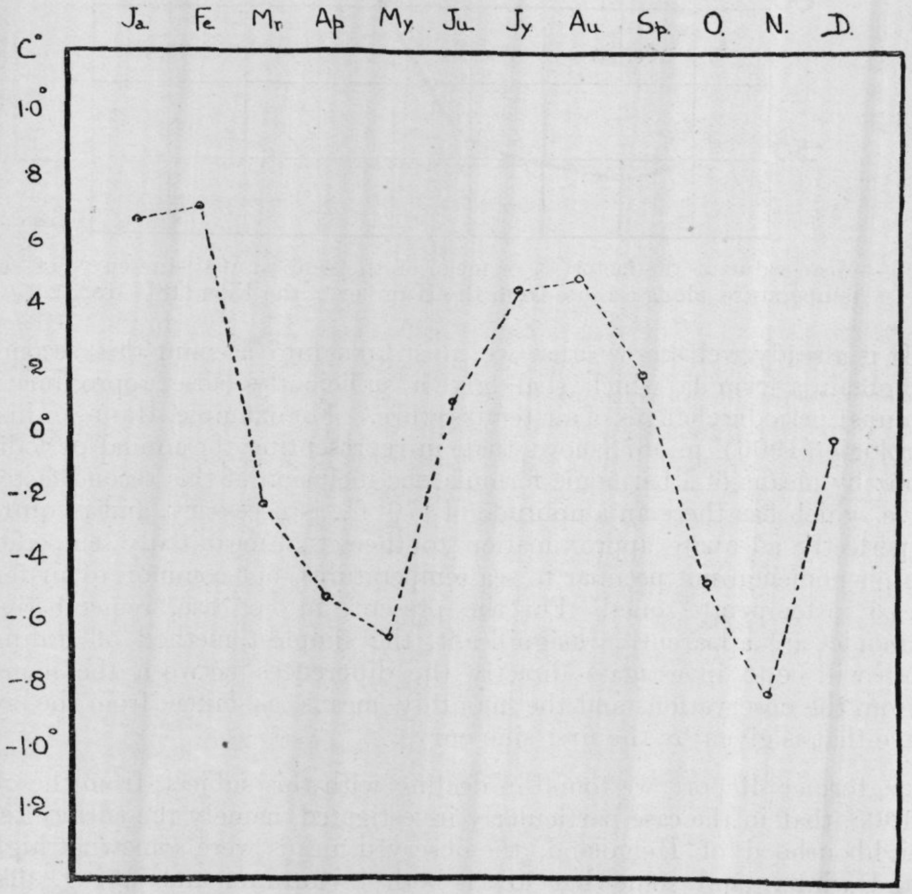

FIG. 7.—Differences between mean monthly air-temperatures at Greenwich as deduced from observations, and as calculated from the fundamental sine-formula.

* Quart. Journ. R. Meteor. Soc., xxv. Oct. 1899.

mean of fifty years' accurate observations, we see that the mean monthly discrepancies from the annual sine-curve form a fairly regular wave, with a total amplitude of about 1·2° C., and with maxima in February and August. The curve for the air-temperatures at Falmouth is not very different from that at Greenwich in respect to phase, but the two semi-annual waves are more markedly unequal, the winter maximum being higher and the summer maximum much lower than in the Greenwich curve.

Next, the curve taken from the sea-temperatures at the Outer Dowsing (1880–97) corresponds closely with those which we have obtained from the more easterly stations on the Hull to Hamburg route, which route indeed passes close by the said lightship (Fig. 8).

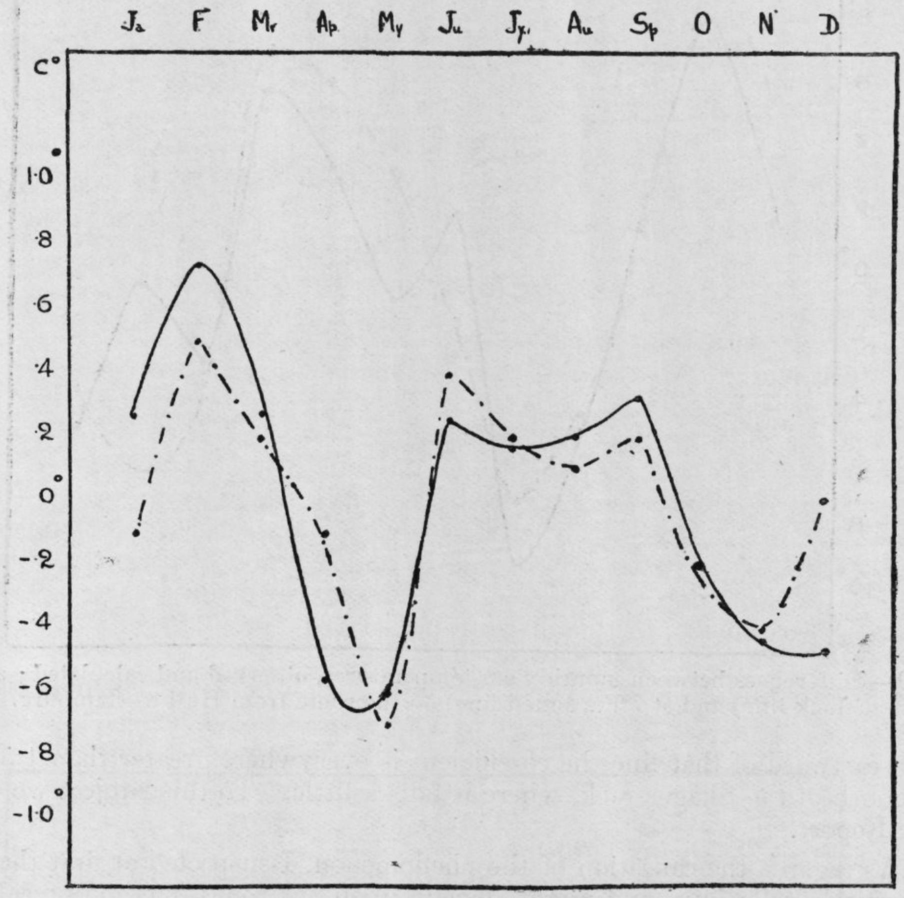

FIG. 8.—Differences between mean monthly sea-temperatures, observed and calculated. At 3° E. on the route from Hull to Hamburg, 1877–1883 (thick line); at the Outer Dowsing, 1880–1897 (dotted line).

A minor feature is reproduced in both curves, viz., a secondary maximum in June, interrupting the ascent of the curve from the April or May minimum to the September maximum; this feature of the curve gradually diminishes as we go eastward along the Hull-Hamburg route, disappears at 6° and 7° E. (Fig. 9), but shows a tendency to reappear at 8° E. At Falmouth, where by the way the observations are doubtless taken in sheltered water, the range for sea-temperature is a little less than at the Outer Dowsing, but the curves are on the whole similar.

Of the Atlantic curves (Fig. 10) that for 40° N., 30° W., near the Azores, has the smallest amplitude; it closely resembles, save for a slight difference in phase, our curve for 7° E. between Hull and Hamburg. In 30° N., 50° W., the curve is again similar, but with somewhat greater amplitude. At 40° N., 55° W., there is a marked difference in the form of a very low minimum in June, so low as to suggest the possibility of an error in the mean temperature assigned to that month. Lastly, a little south of Newfoundland, in 45° N., 55° W., where the mean annual surface-temperature is only 7·4°, and the total annual range about 14°, we have a small and regular curve with total amplitude of nearly 3°, the largest amplitude that we have come across in this connection.

Furthermore, I have plotted upon a chart (not here reproduced) all the values of A_2 given in our former volume of Hydrographic Reports (1904-1905) for various stations in the North Sea during the year 1905, with the interesting result that this factor is found to vary locally in a very regular way, being small everywhere off the Scotch coast, and increasing as we go eastward. If we take a line from the neighbourhood of Bergen to Newcastle, this co-efficient is less than 1·0° C. everywhere in the North Sea to the westward of that line and greater everywhere to the eastward of it; while if we draw a second oblique line parallel to the former from the neighbourhood of Stavanger to Flamborough

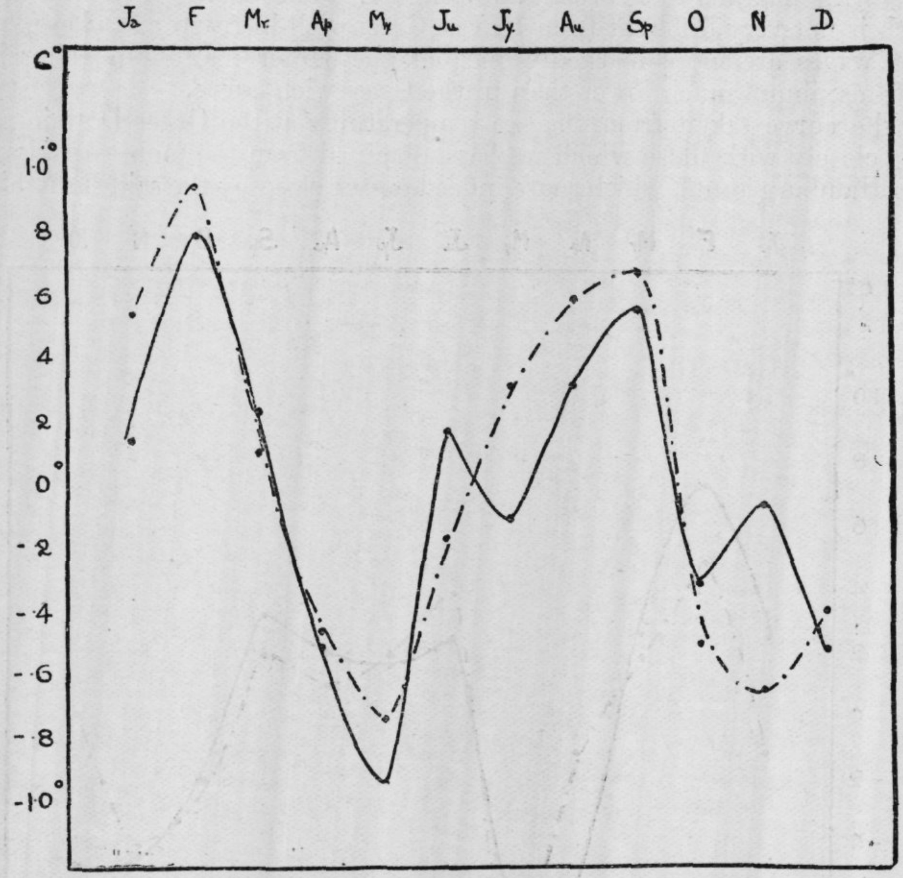

FIG. 9.—Differences between monthly sea-temperatures, observed and calculated; at 1°E. (thick line) and at 7°E. (dotted line) on the route from Hull to Hamburg.

Head, then eastward of that line the co-efficient is everywhere greater than 1·5° C., except near the mouth of the Skager-rack, where it falls a little. To this subject we shall return in another Report.

(9.) As regards the causation of the phenomenon, I suspected at first that the thing might be entirely fallacious, and might depend upon our rough method of calculation, in which we omit to correct for the inequality of the months. This is certainly not the case; the correction for the calendar dates is smaller in amount, and quite different in its nature from the discrepancy with which we are now dealing; it scarcely affects the amplitude, and makes but a trifling difference in phase. It next appeared to me to be possible that a physical cause might be found in the seasonal change in the amount of wind, and in the greater amount of mixing of the waters which takes place in winter owing to the action of waves as compared with what goes on in the calmer seas of summer. Assuming this to be the case, the warming influences in summer are, so to speak, expended upon a more superficial layer of the sea, while the cooling influences of winter affect a larger or deeper body of water; and the result should be just such as we have observed, namely, a retardation of temperature-change in the surface layers during the stormy season of winter, and a comparative acceleration of temperature-change during the calmer weather of summer-time. A similar explanation is equally conceivable in the case of atmospheric temperatures, and it is probable that it has some effect, and certain that its effect, if any, is in the required direction; but this explanation fails to meet the case, or to account adequately for the phenomenon in question. There are two obvious reasons why it is inadequate: firstly, while to the north of the Dogger Bank it is found to be the case that the temperature of the North Sea is practically identical from surface to bottom in the winter-time, but much hotter in the surface than below in summer-time, yet, on the other hand, to the southward of the Dogger Bank this seasonal difference does not exist, for tidal and other currents are at all seasons sufficient to intermix the waters, and to give an identical, or almost identical, temperature from surface to bottom. Secondly, the above explanation quite fails to account for the progressive differences that we have found to exist on the route from Hull to Hamburg, and in general from the west to the east sides of the North Sea. The true explanation probably lies in some simple meteorological phenomenon, probably connected with the direction as well as the force of prevailing winds, but it must be confessed that the problem is as yet unsolved.

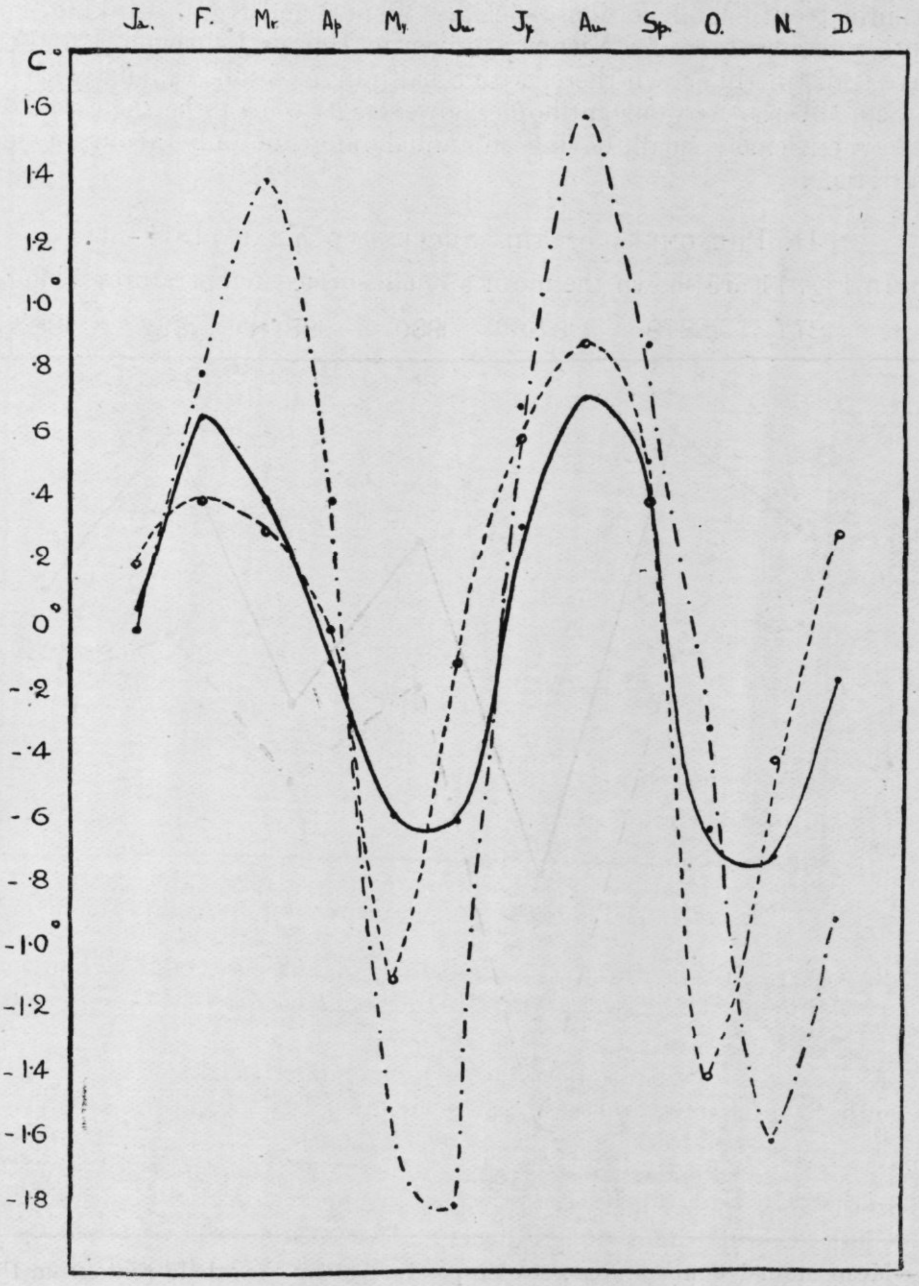

FIG. 10.—Differences between mean monthly temperatures, observed and calculated. Sea-temperatures in Atlantic; at 40° N. 30′ W., near the Azores (thick line); at 30° N. 50′ W. (dotted line ------); at 45° N. 55′ W., south of Newfoundland (dotted line —.—.—).

(9A.) Since the rest of this paper was completed I find that the question of the semi-annual wave has already been discussed by Dr. W. N. Shaw and Mr. R. W. Cohen, in a paper on "The Seasonal Variation of Atmospheric Temperature in the British Isles and its Relation to Wind-direction, with a Note on the Effect of Sea Temperature on the Seasonal Variation of Air Temperature."*

These authors give a clear account of the phenomenon, and show that it is independent of the relative frequency of occurrence of cyclonic and anticyclonic weather. They consider that it is partly due to a periodic variation in the relative frequency of "cold" "warm" and "temperate" winds, the lowering of temperature in May, and to some extent in November, being (for instance) synchronous with a marked increase of cold northerly and easterly winds. They show also that a similar periodic variation of the second order is found in the case of the magnitude of the barometric gradient between London and Valencia and between London and Aberdeen, those gradients showing well-marked maxima about the middle of January and the middle of July; and they consider it

* Proc. Roy. Soc., Vol. LXIX., pp. 61–85, 1902.

probable that this periodic variation in pressure plays some part in causing the similar variation in temperature.

They state that this semi-annual variation is not found, with maxima at the same epoch, in purely continental stations, such as Vienna and Agra. Taking, however, the mean monthly temperatures for Vienna as given in Hann's Lehrbuch, I find that a semi-annual wave is distinctly shown there, with a half-range of ·53° C., and with maxima in April and September. At Constantinople, however, it seems to be the case that the semi-annual wave is extremely small, having an annual range of only about one-eighth of a degree Centigrade.

II. Phenomena of the Successive Years 1877–83.

(10.) In Fig. 11 are shown the mean annual surface temperatures along our route

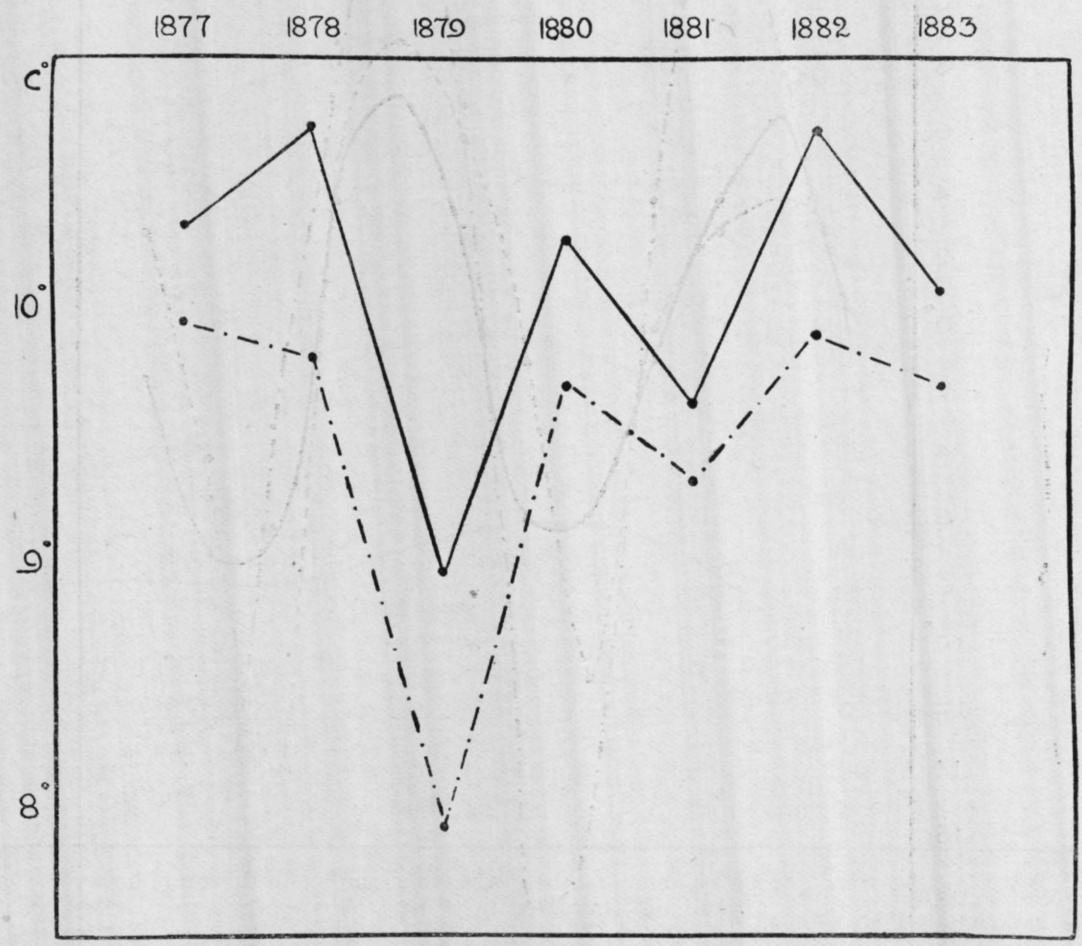

Fig. 11.—Mean annual temperatures: sea-temperature along the whole route from the Humber to the Elbe (thick line); air-temperature at Greenwich (dotted line).

from 1° to 8° East for the years 1877–1883, and side by side with them are plotted the mean air-temperatures at Greenwich for the same years. It will be seen that the two series are closely parallel. The mean excess of sea-temperature over air-temperature over the whole seven years was ·65° C.; and the greatest discrepancy was in the very cold year 1879, when the mean sea-temperature was 1·5° above the mean air-temperature at Greenwich. Comparing, in the next place, the Greenwich air-temperatures with the surface-temperatures at our nearest station to the English coast, namely in 1° East, the mean difference is only ·11° Centigrade, and the greatest discrepancy is again in the year 1879, when the sea-temperature was ·41° in excess of the Greenwich air-temperature. This is, on the whole, in conformity with the result arrived at by Mr. Dickson in his paper already quoted, viz., that on the East Coast of England the mean annual temperature of the sea-surface is ·2° F. in excess of the air-temperature, a difference which, however, is much exceeded on our southern and western coasts. In 1877 and in 1881 the mean temperature of the surface water would appear to be slightly below the air-temperature at Greenwich, but our results, especially at this most easterly station, are far from being exact enough to let us be certain upon this point. The mean annual surface-temperature of the sea and the mean annual temperature of the air on land show at least such marked correspondence that, so far as surface-temperature by itself is or is likely to be a factor influencing, for instance, the Herring fishery, we may evidently draw approximate conclusions as to how that surface-temperature has varied in past years simply from the air-temperatures, regarding which our information is so much more abundant and accurate. Moreover, since it has been shown that in the southern part of the North Sea, south of the Dogger Bank, the sea-temperature is nearly constant from surface to bottom, we may say that the air-temperature gives a very considerable clue at least to the mean annual temperature of the whole of this part of the sea.

(11.) In Fig. 12 are shown side by side the mean annual temperatures at all points

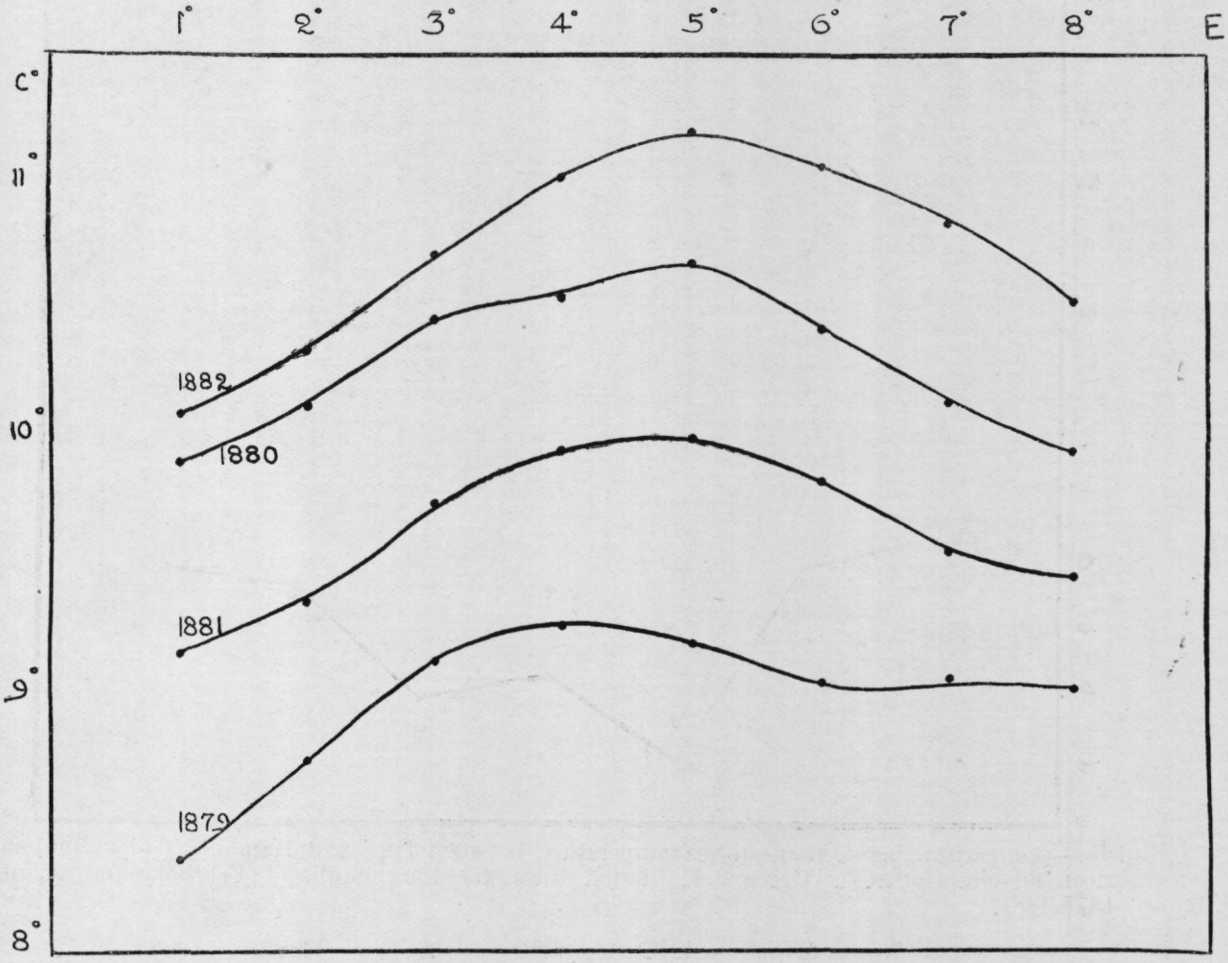

FIG. 12.—Mean annual sea-temperature at successive points on the route between Hull and Hamburg, in various years.

along our route for four out of the seven years which we have studied. It will be seen that the curve is very much the same in all years, the mean temperature being lowest at the western or English end of the route and highest somewhere near the middle : but we see, or seem to see from this figure, the further fact that the point of highest mean temperature is shifted somewhat further to the westward the lower the mean temperature of the year.

(12.) When we compare month by month, instead of merely year by year, the Greenwich air-temperatures with the mean surface-temperatures along our route we still see, for the most part, but with certain striking exceptions, a close correspondence between them. This correspondence will be best exhibited by drawing curves for each separate month during the successive years for which we have observations at sea.

We then find, in the first place, that in the months of February and August (Fig. 13) the Greenwich air-temperature is always nearly identical with the mean sea-temperature. On the other hand, as Mr. Dickson has shown, from March to July (or longer) the sea-temperature, rising more slowly, is always much below the air-temperature, while from September to January it is, conversely, considerably above the air-temperature. This marked difference is illustrated by curves drawn for the months of April and October (Fig. 14).

The phenomenon is a simple corollary to the facts that the annual waves of air-temperature and of sea-temperature are both approximately sine-curves, that their means and amplitudes are approximately identical, and that the former precedes the latter in

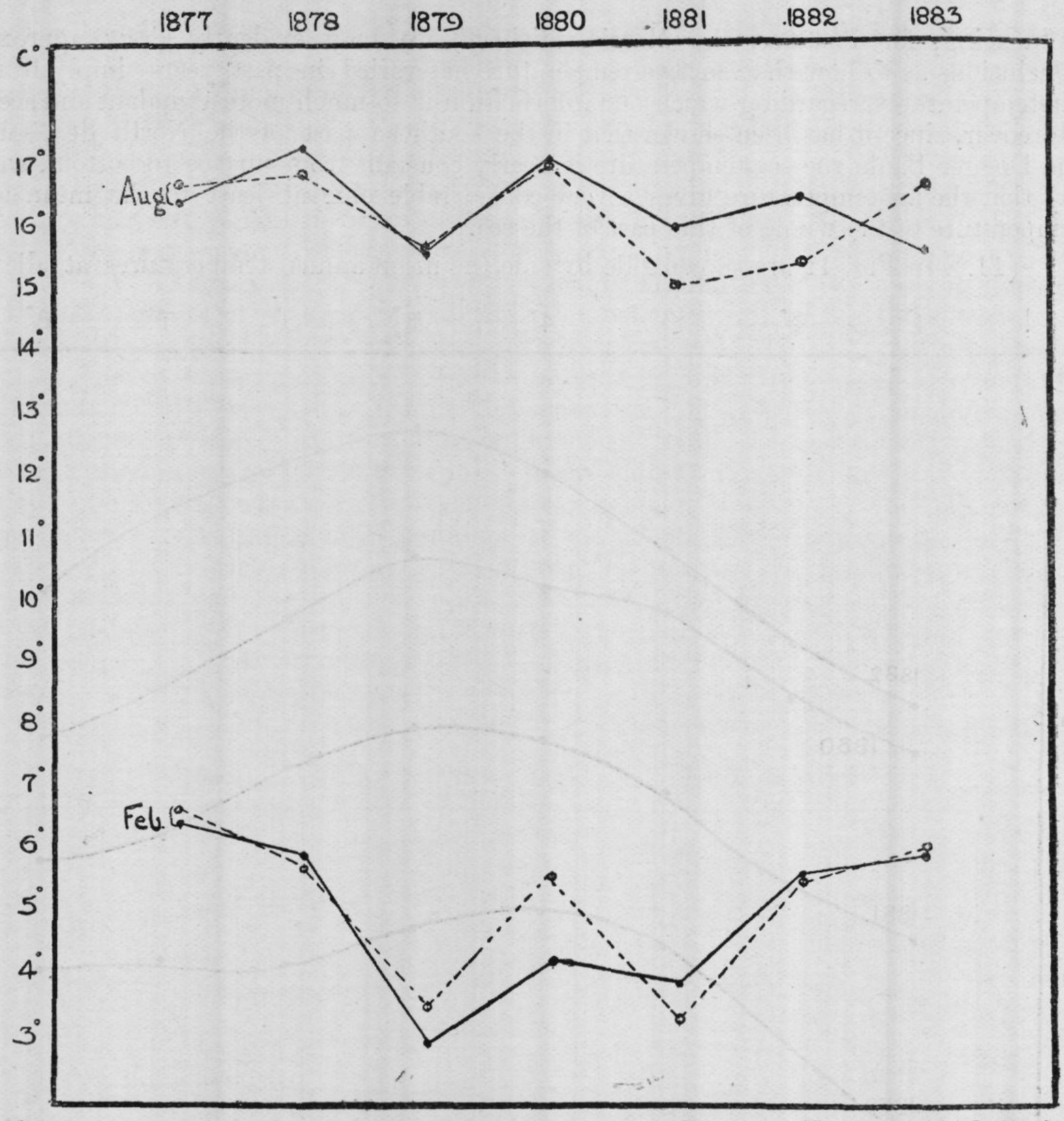

FIG. 13.—Comparison between mean sea-temperature between Hull and Hamburg (thick line) and mean air-temperature at Greenwich (dotted line), for the months of February and August 1877–1883.

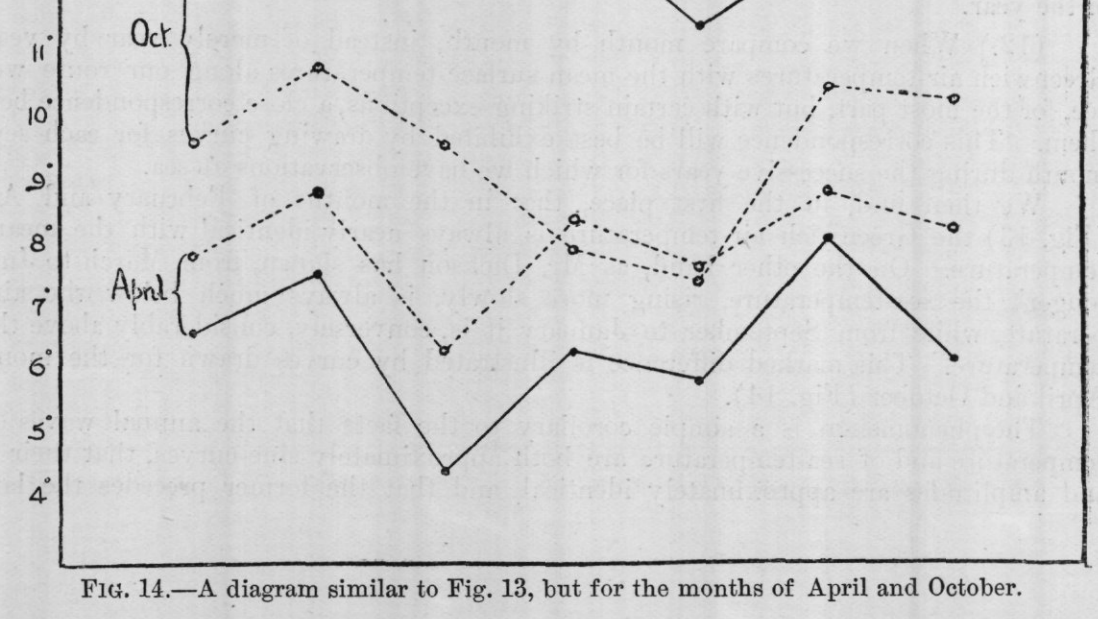

FIG. 14.—A diagram similar to Fig. 13, but for the months of April and October.

phase by about three weeks. We may easily determine the nodes, or dates when the two temperatures are identical, by equating the two sine-formulæ for air- and sea-temperature. Doing this with our formulæ for air-temperature at Greenwich and for sea-temperature at the Outer Dowsing, we find that the two temperatures are equal at or about February 12th and August 12th, and that from the former to the latter date the sea-temperature is in excess—a result which is subject to further correction on account of the second harmonic. It is plain that if the *amplitudes* of the two waves were markedly unequal the periods during which the sea-temperature is above and below the air-temperature would still last for one-half the year, but would be transposed to very different seasons.

On the other hand, if the mean temperatures be markedly dissimilar, then it may well happen that the two curves will never intersect; and this is the case, to judge from Mr. Dickson's figures, with the air- and sea-temperature of the west of Ireland, where the phase is practically identical, but the mean sea-temperature is about ·8° C. above that of the land; the amplitudes differ by about ·3° C. If in this case we equate the two formulæ, we arrive at an impossible result, and, as a matter of fact, observation shows that the sea-temperature is in excess of the air-temperature all the year round.

While in nearly all cases the curves for air and sea-temperature run approximately parallel to one another, yet on the whole we find, as we might naturally expect, that the fluctuations of the mean air-temperature are somewhat greater than those of the mean sea-temperature. And in two instances, namely, in July and in November, 1881, we have abnormally high mean air-temperatures which are not in the least degree repeated on the sea-temperature curves (Fig. 15). Both were exceptional months: November, 1881, was the warmest November at Greenwich, with two exceptions, for 110 years, while

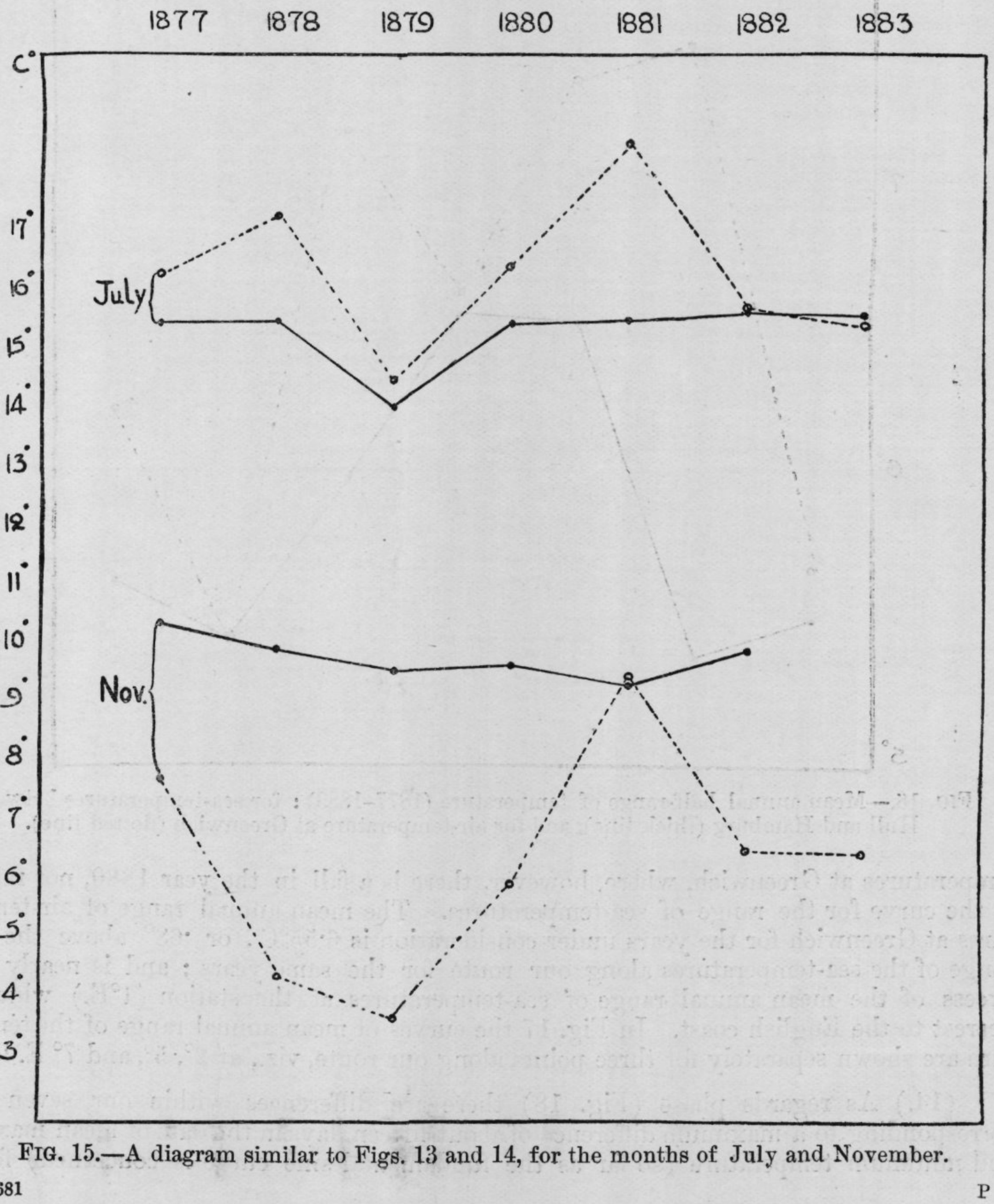

FIG. 15.—A diagram similar to Figs. 13 and 14, for the months of July and November.

July, 1881, was also extraordinarily hot, but not uniformly so, for in the west and south-west of England it was rather below the average. It is noteworthy that October, 1881, which was an exceptionally cold month, shows its low temperature both upon the air curve and upon the sea curve, while the high temperature of the immediately following November is only indicated on the former.

The same curves (if we complete the series for the remaining months) will be found interesting in comparing the characters of the various years. In 1879, which was on the average the coldest year of our series, its exceptionally low temperature is reflected in every month until September, but from September onwards the monthly temperatures are as low, or lower, in certain other years. In 1881, which is the next coldest year, on the average, of our series, every month, with the exception of December, is again more or less exceptionally cold, and September and October are remarkably so. The year 1878, which is by a little the hottest year of the series, owes its high mean temperature chiefly to the spring and autumn months, the range of temperature being below the average in that year; and the same is the case in 1882, when the mean temperature was again high, and the range low.

(13.) The mean annual range of temperature (deduced as usual from the fundamental sine curve) is highest for the year 1879 and 1880, of which the former was the coldest year of the series, and lowest for the years 1877, 1878, and 1882, which were the three hottest (Fig. 16). The variation from year to year is on the whole similar in the air-

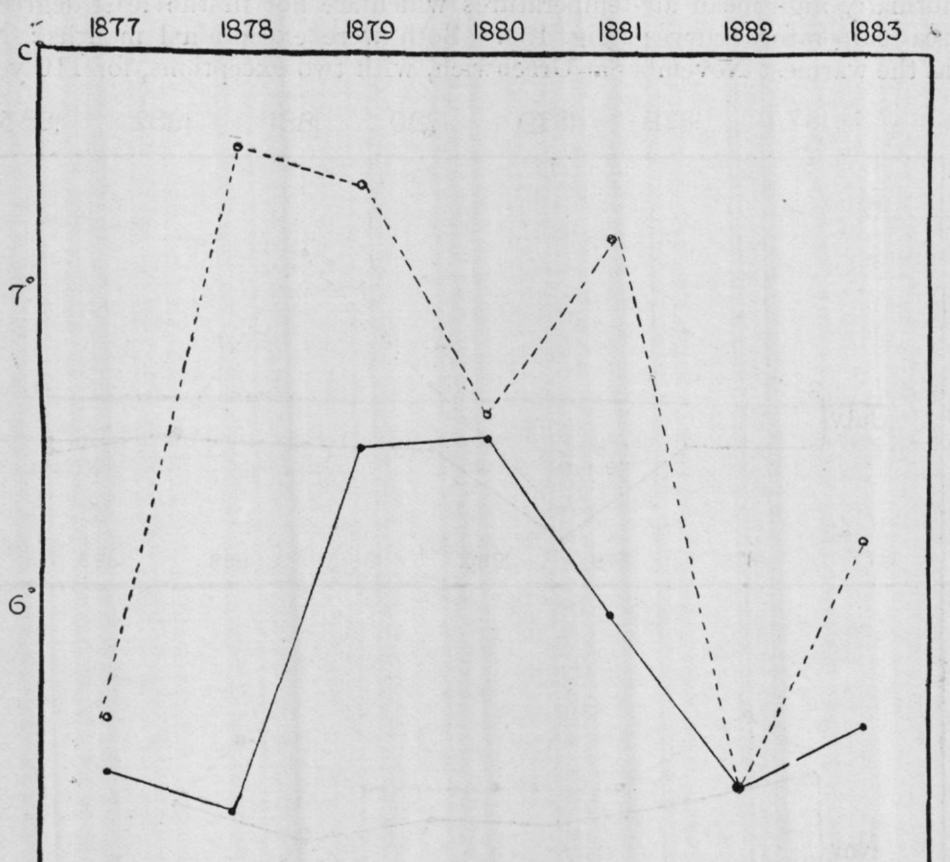

FIG. 16.—Mean annual half-range of temperature (1877–1883): for sea-temperatures between Hull and Hamburg (thick line), and for air-temperature at Greenwich (dotted line).

temperatures at Greenwich, where, however, there is a fall in the year 1880, not reflected in the curve for the range of sea-temperatures. The mean annual range of air-temperatures at Greenwich for the years under consideration is 6·55°C, or ·68° above the mean range of the sea-temperatures along our route for the same years; and is nearly 2° in excess of the mean annual range of sea-temperatures at the station (1°E.) which lies nearest to the English coast. In Fig. 17 the curves of mean annual range of the temperature are shown separately for three points along our route, viz., at 2°, 5°, and 7° E. long.

(14.) As regards phase (Fig. 18) there are differences within our seven years corresponding to a maximum difference of about fifteen days in the date of mean maximum and minimum temperature (so far as the fundamental sine curve is concerned) for our

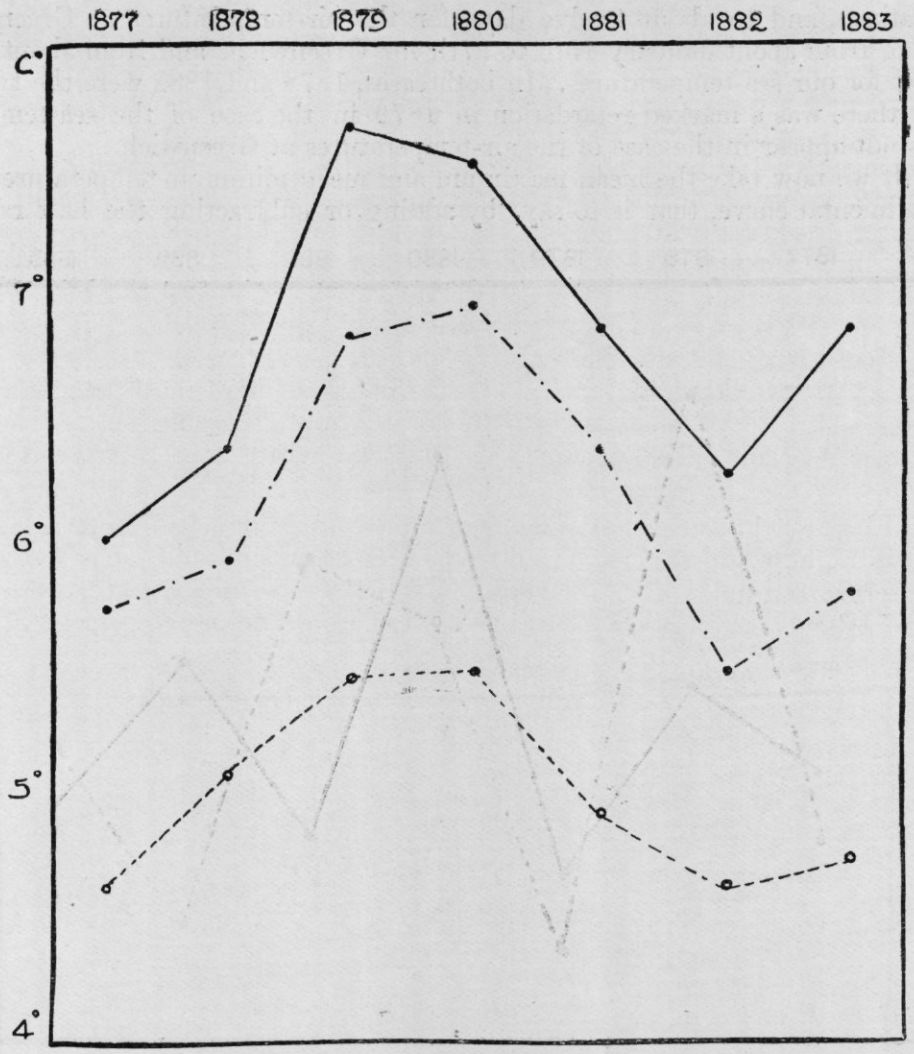

FIG. 17.—Mean annual half-range of sea-temperature (1877–1883), at points on the route between Hull and Hamburg: at 7° E. (uppermost curve), 5° E. (middle), and 2° E. (lowermost curve).

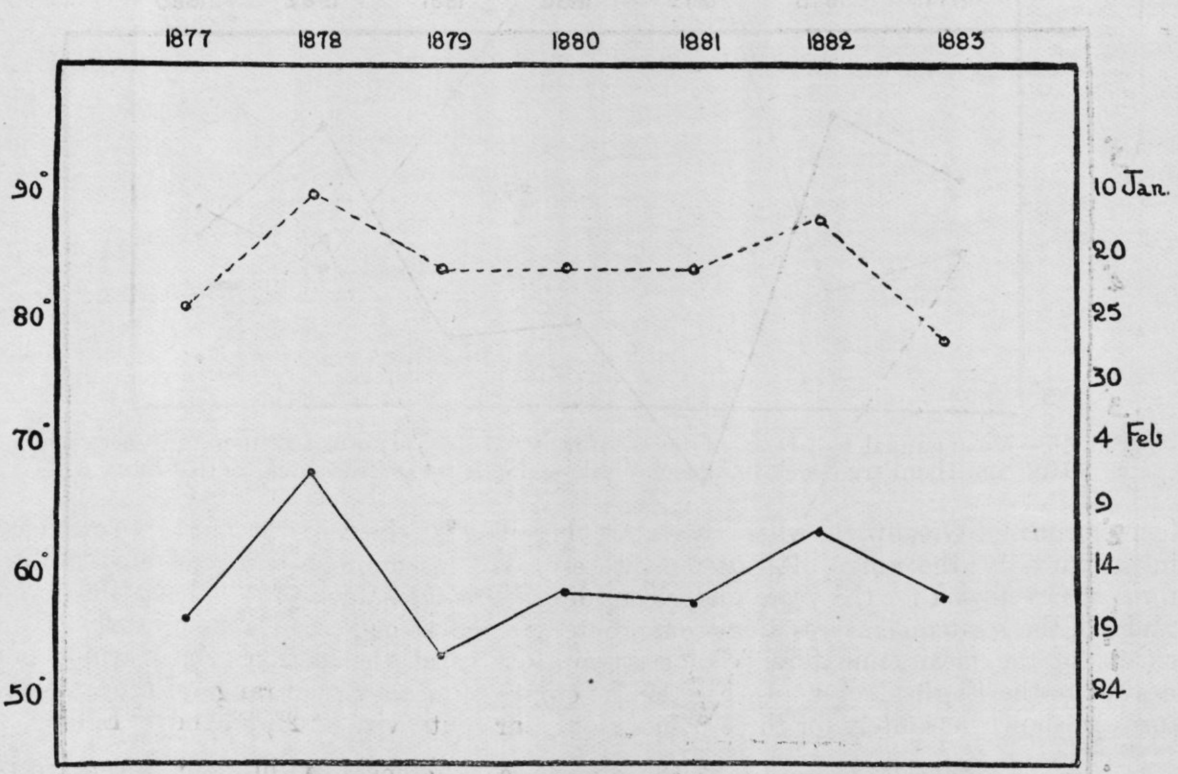

FIG. 18.—Diagram showing phase differences for successive years between sea-temperatures along our route (thick line), and air-temperatures at Greenwich (dotted line). The dates correspond to the epoch of minimal temperature, as determined by the fundamental sine-curve.

sea-temperatures, and to about twelve days for the air-temperatures at Greenwich, the periods being from about January 15th to 27th for Greenwich, and from about February 11th to 21st for our sea-temperatures. In both cases, 1878 and 1882 were the two earliest years; but there was a marked retardation in 1879 in the case of the sea-temperatures, which does not appear in the case of the air-temperatures at Greenwich.

(15.) If we now take the mean maximum and mean minimum temperatures as given by the funadmental curve, that is to say, by adding or subtracting the half range to or

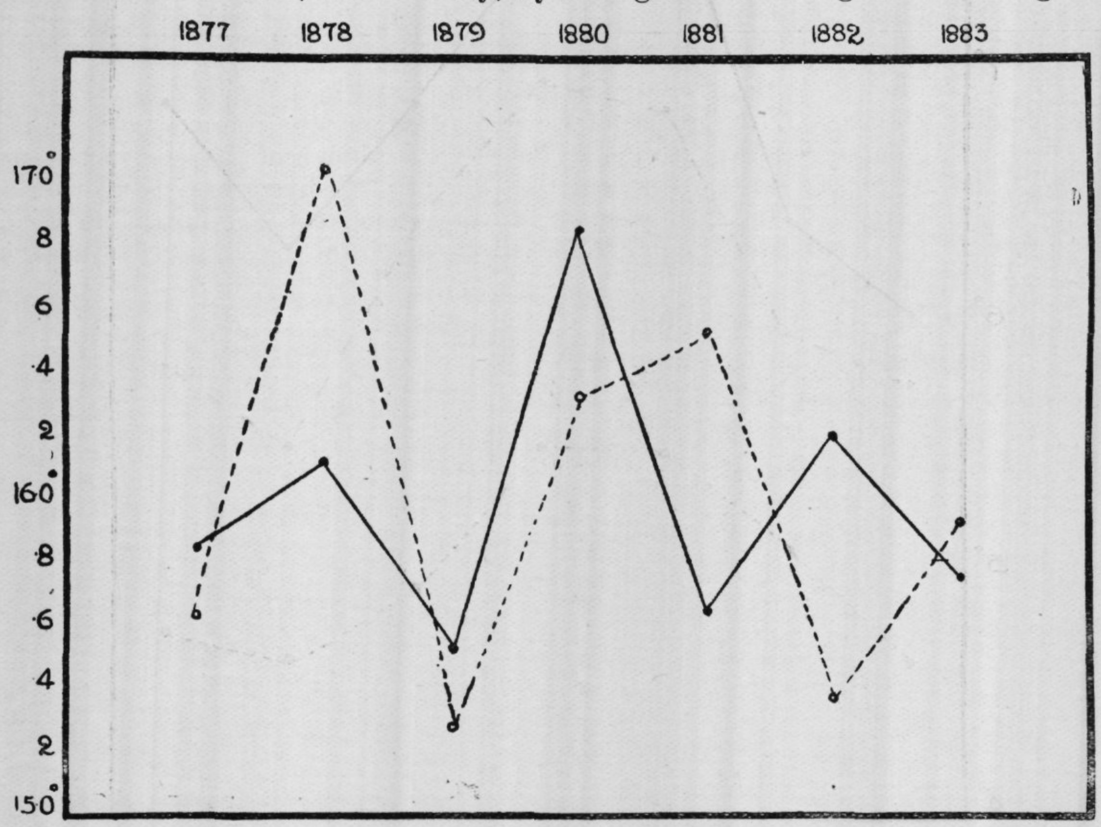

FIG. 19.—Mean maximum temperatures in successive years: sea-temperature between Hull and Hamburg (thick line), air-temperature at Greenwich (dotted line).

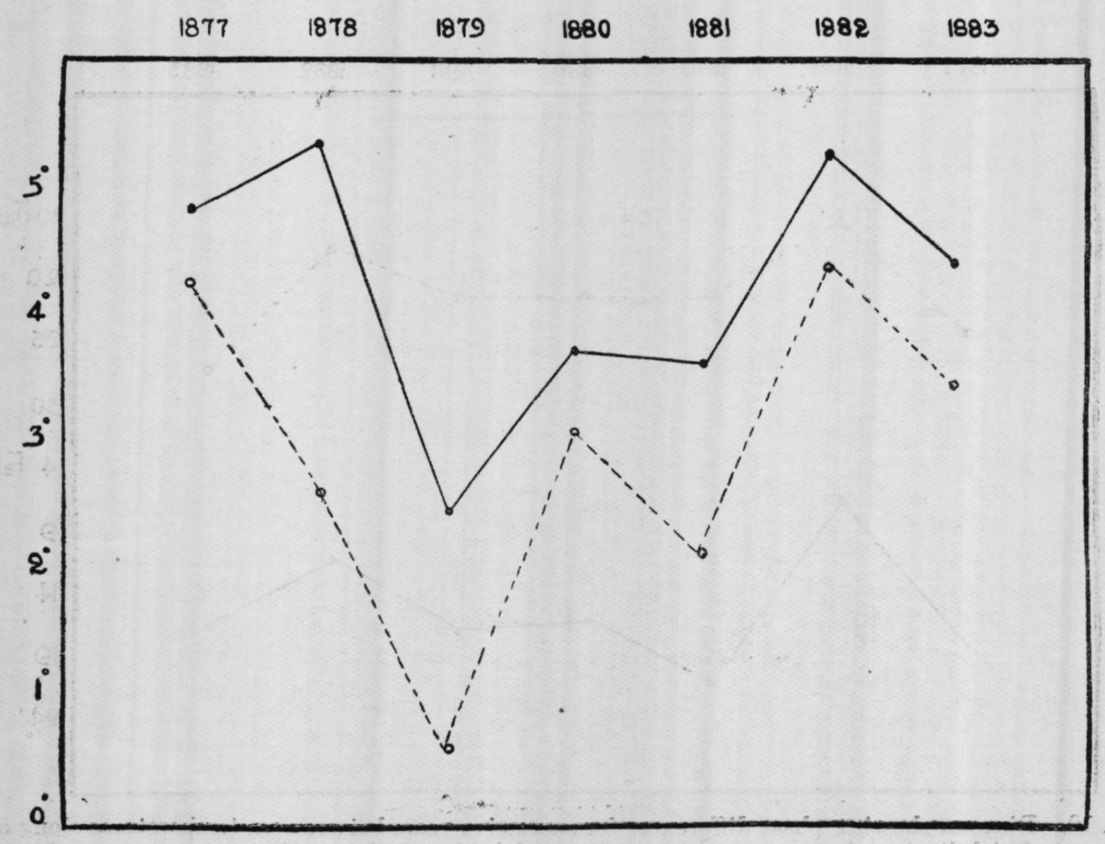

FIG. 20.—Mean minimum temperatures in successive years: sea-temperature between Hull and Hamburg (thick line), air-temperature at Greenwich (dotted line).

from the mean temperature of the year, we find a striking difference between the two as regards the relations of the sea and air-temperatures.

In the case of mean maximum (Fig. 19) there is no constant difference between the results for the Greenwich air-temperatures and for our sea-temperatures during the seven years. The two curves for the successive years intersect one another, and while during five out of the seven years they seem to vary consistently, during the other two they fail to agree, seeming rather to vary in inverse relation to one another. The extreme variation in the case of the sea-temperatures is about 1·3° C., and that of the air-temperatures about 1·7°.

(16.) In the case of the mean minimum temperatures (Fig. 20) the total variation is larger, amounting to about 4° in the case of the Greenwich air-temperatures, and about 3° in the case of our sea-temperature; secondly, the mean minimum of the sea-temperatures is about 1·3° higher for the sea-temperatures than for the air-temperatures; and, thirdly, with one slight exception, the two phenomena vary from year to year in an almost identical fashion. In both cases the minimum was by much the lowest in 1879, and was highest in 1878 and 1882.

TABLE I.

HULL TO HAMBURG. MONTHLY MEAN SEA-TEMPERATURES AT SURFACE, 1877–1883

Longitude E.	1°	2°	3°	4°	5°	6°	7°	8°	Mean.
1877.									
January	5·8	6·0	6·0	6·0	5·8	5·5	4·9	4·4	5·55
February	7·1	7·0	6·9	6·6	6·3	6·1	5·9	5·6	6·44
March	6·1	6·1	6·0	6·0	5·8	5·6	5·1	4·8	5·69
April...	6·7	6·8	6·9	6·7	6·6	6·6	6·2	6·5	6·63
May	8·5	8·4	8·4	8·7	8·7	8·8	8·8	8·7	8·63
June	12·3	12·8	13·2	13·6	14·1	13·7	13·8	14·7	13·53
July	13·6	14·5	15·1	15·6	15·8	16·1	16·5	16·8	15·5
August	14·5	14·9	15·9	16·6	17·1	17·5	17·7	17·4	16·45
September	14·4	14·7	15·0	15·3	15·7	15·9	15·7	15·9	15·33
October	11·4	11·6	12·3	13·1	13·2	12·9	12·7	12·7	12·49
November	9·8	10·5	10·6	11·1	10·8	10·3	10·0	10·1	10·4
December	7·6	7·8	7·8	8·0	8·1	7·6	6·9	6·4	7·52
1878.									
January	5·50	6·30	6·55	6·70	6·40	6·20	6·00	5·10	6·11
February	6·05	6·30	6·30	6·30	6·30	6·05	5·60	4·50	5·93
March	6·00	6·10	6·10	6·10	6·00	5·90	5·60	4·90	5·84
April...	6·70	6·95	7·50	7·70	8·00	8·10	8·00	7·80	7·59
May	9·85	9·95	10·20	10·40	10·50	10·65	10·50	10·40	10·31
June	12·40	12·50	12·90	13·20	13·20	13·40	13·70	14·00	13·16
July	13·70	14·90	15·50	15·70	15·75	16·00	16·20	16·60	15·54
August	15·65	16·20	16·80	17·50	18·00	18·20	18·30	18·40	17·38
September	14·5	15·2	15·9	16·7	17·15	14·45	17·3	17·0	16·03
October	13·1	13·45	14·0	14·5	14·6	14·5	14·0	13·5	13·96
November	9·1	9·85	10·4	10·8	10·9	10·6	9·7	8·5	9·98
December	6·7	8·8	7·5	7·7	7·6	7·0	6·5	5·5	7·16
1879.									
January	4·35	4·7	5·1	5·0	4·8	4·4	4·0	3·3	4·46
February	3·30	3·3	3·4	3·4	3·1	2·7	2·5	2·1	2·98
March	4·00	4·0	3·9	3·5	3·2	2·5	2·0	1·8	3·11
April...	4·90	4·9	4·8	4·6	4·1	4·0	4·0	4·1	4·43
May	7·80	7·7	7·7	7·8	7·8	7·8	8·5	9·0	8·01
June	10·50	10·6	10·9	11·7	12·1	12·2	13·1	14·8	11·99
July	11·90	12·5	13·4	14·0	14·4	15·0	15·5	15·9	14·08
August	13·35	14·2	15·0	15·5	16·1	16·5	17·0	17·3	15·62
September	13·1	13·9	14·8	15·3	15·8	16·1	16·2	16·1	15·16
October	11·75	12·5	13·5	13·9	13·8	13·7	13·3	12·5	13·12
November	9·30	10·1	10·4	10·4	10·0	9·5	8·9	7·9	9·56
December	5·80	6·4	6·6	6·2	5·2	4·2	3·8	3·4	5·20
1880.									
January	5·4	5·7	5·3	5·2	4·8	4·0	3·0	2·4	4·48
February	5·2	5·2	5·5	4·7	4·2	3·6	3·2	2·4	4·25
March	6·0	5·9	5·7	5·6	5·4	5·0	4·4	4·2	5·28
April...	6·6	6·6	6·3	6·2	6·2	6·1	6·0	6·6	6·33
May	9·1	9·1	9·1	9·3	9·3	9·2	9·6	10·8	9·44
June	12·5	12·4	13·6	13·5	13·7	13·7	13·9	14·8	13·51
July	13·7	14·0	14·6	15·3	16·0	16·3	16·3	17·5	15·46
August	15·2	16·0	16·5	16·9	17·5	18·2	18·1	18·8	17·15
September	16·2	16·5	17·2	17·7	18·2	18·1	17·8	17·3	17·38
October	12·2	12·9	13·6	14·1	14·1	13·5	13·4	11·5	13·16
November	9·3	9·8	10·6	10·4	10·3	9·7	9·2	7·6	9·61
December	7·4	7·5	7·7	7·8	7·9	7·8	7·0	5·6	7·34

TABLE I—*continued.*

HULL TO HAMBURG. MONTHLY MEAN SEA-TEMPERATURES AT SURFACE, 1877–1883—*continued.*

Longitude E.	1°	2°	3°	4°	5°	6°	7°	8°	Mean.
1881.									
January	5·4	5·6	5·7	5·4	5·2	4·9	4·5	3·6	5·04
February	4·9	4·8	4·7	4·3	3·8	3·2	2·9	2·4	3·88
March	4·3	4·6	4·7	4·6	4·1	3·8	3·1	2·9	4·01
April...	6·1	6·0	5·9	5·8	5·7	5·7	5·8	6·0	5·88
May	8·6	8·4	8·5	8·6	8·6	8·5	8·5	9·1	8·60
June	12·4	12·6	12·9	12·9	12·8	12·6	12·5	14·1	12·85
July	13·7	13·9	14·9	15·7	16·5	16·4	16·3	17·0	15·55
August	14·4	14·7	15·0	15·9	16·7	17·1	17·2	17·3	16·01
September	13·1	13·7	14·4	15·2	15·7	15·9	16·0	15·8	14·98
October	10·3	10·4	11·9	12·4	12·4	12·3	11·7	10·9	11·54
November	9·0	9·6	9·8	9·9	9·7	9·1	8·9	8·4	9·30
December	7·8	8·0	8·4	8·7	8·8	8·3	7·3	6·1	7·93
1882.									
January	6·9	7·0	7·1	7·2	7·1	6·8	6·1	4·7	6·61
February	5·9	6·1	6·2	6·2	6·1	5·8	4·9	3·9	5·64
March	6·9	6·9	6·9	7·0	6·9	6·8	6·5	6·5	6·80
April...	7·8	7·6	7·8	8·2	8·6	8·7	8·6	8·2	8·19
May	9·6	9·6	9·8	10·4	11·0	11·0	11·1	11·5	10·50
June	11·6	12·1	12·9	13·5	13·8	14·0	14·1	15·0	13·38
July	13·5	14·0	14·6	15·4	16·2	16·7	17·1	17·9	15·68
August	15·2	15·4	16·0	16·6	16·9	17·1	17·5	17·8	16·56
September	15·2	15·4	15·8	16·2	16·6	16·8	16·9	16·6	16·19
October	12·4	12·8	13·3	13·7	13·6	12·8	12·4	11·6	12·83
November	9·7	10·0	10·5	10·7	10·5	9·8	9·4	8·7	9·91
December	6·5	7·3	7·7	7·4	7·2	6·7	5·7	4·2	6·59
1883.									
January	6·8	6·9	7·0	6·9	6·1	5·1	4·2	3·5	5·81
February	6·8	7·0	6·8	6·7	6·0	5·2	4·6	4·1	5·90
March	5·7	5·7	5·6	5·4	5·1	4·5	3·9	3·2	4·89
April...	6·5	6·6	6·6	6·3	6·0	6·0	5·8	5·9	6·21
May	8·7	9·0	9·2	9·5	9·4	9·2	9·4	10·6	9·38
June	11·7	11·7	12·3	12·9	13·0	12·9	13·1	14·6	12·78
July	14·1	14·1	14·6	15·1	15·7	16·7	16·9	17·7	15·61
August	14·2	14·4	14·8	15·6	16·0	16·2	16·8	17·1	15·64
September	14·1	14·4	14·8	15·8	16·2	16·4	16·5	16·3	15·56
MEANS, JANUARY 1877—SEPTEMBER 1883.									
January	5·74	6·03	6·12	6·06	5·74	5·27	4·67	3·86	5·44
February	5·61	5·67	5·69	5·46	5·12	4·66	4·23	3·57	5·00
March	5·57	5·62	5·56	5·46	5·22	4·87	4·37	4.04	5·09
April...	6·47	6·49	6·54	6·50	6·46	6·46	6·34	6·44	6·46
May	8·88	8·88	8·99	9·24	9·33	9·31	9·49	10·01	9·27
June	11·91	12·1	12·67	13·04	13·26	13·22	13·46	14·57	13·03
July	13·46	13·99	14·67	15·26	15·76	16·17	16·40	17·06	15·35
August	14·65	15·12	15·72	16·37	16·9	17·26	17·52	17·73	16·41
September	14·37	14·83	15·42	16·03	16·48	16·24	16·63	16·43	15·80
October	11·86	12·28	13·10	13·62	13·62	13·28	12·92	12·12	12·84
November	9·37	9·97	10·40	10·6	10·4	9·80	9·35	8·53	9·80
December	6·90	7·63	7·62	7·63	7·47	6·93	6·20	5·20	6·95
Year	9·57	9·88	10·21	10·44	10·48	10·29	10·10	9·96	10·12

TABLE II.

HULL TO HAMBURG. MEAN ANNUAL SEA-TEMPERATURES AT SURFACE, 1877–1883.

Longitude E.	1°	2°	3°	4°	5°	6°	7°	8°	Mean.
1877	9·82	10·09	10·34	10·61	10·67	10·55	10·35	10·33	10·34
1878	9·94	10·54	10·81	11·11	11·20	10·92	10·95	10·52	10·75
1879	8·34	8·73	9·13	9·28	9·20	9·05	9·07	9·02	8·98
1880	9·90	10·13	10·48	10·56	10·70	10·43	10·16	9·96	10·29
1881	9·17	9·36	9·73	9·95	10·00	9·82	9·56	9·47	9·63
1882	10·10	10·35	10·72	11·04	11·21	11·08	10·86	10·55	10·74
1883*...	9·77	9·99	10·27	10·50	10·40	10·13	9·89	9·79	10·09
1877-1883	9·57	9·88	10·21	10·44	10·48	10·29	10·12	9·96	10·12
Difference from mean ...	—·55	—·24	·09	·32	·36	·17	·00	—·16	—

*October 1882—October 1883.

TABLE III.

HARMONIC CONSTANTS DERIVED FROM MEAN MONTHLY SEA-TEMPERATURES AT VARIOUS POINTS ALONG THE ROUTE FROM HULL TO HAMBURG.

Longitude.	A_0.	A_1.	e_1.	Approximate date of Minimum.	Mean Maximum.	Mean Minimum.	A_2.	e_2.
				1877.				
			° ′					°
1° E. ...	9·82	4·35	56 35	February 17	14·17	5·47	0·72	38 8
2° E. ...	10·09	4·62	55 52	„ 18	14·71	5·47	0·74	51 34
3° E. ...	10·34	5·03	55 52	„ 18	15·37	5·31	0·84	48 53
4° E. ...	10·61	5·42	54 51	„ 19	16·03	5·19	0·76	53 35
5° E. ...	10·67	5·74	55 44	„ 18	16·41	4·93	0·82	55 55
6° E. ...	10·55	5·95	57 29	„ 17	16·50	4·60	0·98	46 14
7° E. ...	10·35	6·01	57 51	„ 16	16·36	4·34	1·08	48 46
8° E. ...	10·33	6·56	61 31	„ 12	16·89	3·77	0·91	52 38
				1878.				
			° ′					° ′
1° E. ...	9·94	5·01	60 1	February 14	14·95	4·93	0·59	1 15
2° E. ...	10·54	5·07	55 7	„ 19	15·61	5·47	0·53	42 33
3° E. ...	10·81	5·44	57 10	„ 17	16·25	5·37	0·62	15 40
4° E. ...	11·11	5·74	56 11	„ 18	16·85	5·37	0·66	8 3
5° E. ...	11·20	5·93	56 31	„ 17	17·13	5·27	0·76	— 2 16
6° E. ...	10·92	5·74	61 5	„ 13	16·66	5·18	0·71	15 26
7° E. ...	10·95	6·38	61 37	„ 12	17·33	4·57	0·93	7 9
8° E. ...	10·52	6·70	70 38	„ 3	17·22	3·82	0·94	12 12
				1879.				
			° ′					° ′
1° E. ...	8·34	5·09	52 11	February 22	13·43	3·25	0·18	—73 0
2° E. ..	8·73	5·46	48 47	„ 25	14·19	3·27	0·16	—55 14
3° E. ...	9·13	5·93	47 20	„ 27	15·06	3·20	0·22	10 18
4° E. ...	9·27	6·43	48 29	„ 26	15·70	2·84	0·38	10 43
5° E. ...	9·20	6·83	51 25	„ 23	16·03	2·37	0·49	22 53
6° E. ...	9·05	7·31	53 51	„ 20	16·36	1·74	0·63	24 31
7° E. ...	9·07	7·68	57 49	„ 16	16·75	1·39	0·65	41 16
8° E. ...	9·02	8·93	66 5	„ 8	17·95	0·09	0·74	11 50

TABLE III—*continued*.

Harmonic constants derived from Mean Monthly Sea-temperatures at various points along the route from Hull to Hamburg—*continued*.

Longitude.	A_0.	A_1.	e_1.	Approximate date of Minimum.	Mean Maximum.	Mean Minimum.	A_2.	e_2.
				1880.				
1° E. ...	9·90	5·24	57° 9′	February 17	15·14	4·66	0·62	1° 50′
2° E. ...	10·13	5·48	54 40	„ 19	15·61	4·65	0·69	10 39
3° E. ...	10·47	5·97	53 52	„ 20	16·44	4·50	0·56	6 7
4° E. ...	10·56	6·40	54 1	„ 20	16·96	4·16	0·56	2 3
5° E. ...	10·70	6·95	55 34	„ 18	17·65	3·75	0·63	20 27
6° E. ...	10·43	7·22	57 2	„ 17	17·65	3·21	0·69	18 42
7° E. ...	10·16	7·53	59 52	„ 14	17·69	2·63	0·56	10 18
8° E. ...	9·96	8·08	69 26	„ 5	18·04	1·88	0·71	38 9
				1881.				
1° E. ...	9·17	4·79	59° 22′	February 15	13·96	4·38	0·84	27° 8′
2° E. ...	9·27	4·91	57 13	„ 17	14·18	4·36	0·85	22 33
3° E. ...	9·73	5·34	54 55	„ 19	15·07	4·39	0·85	12 27
4° E. ...	9·95	5·87	54 17	„ 20	15·82	4·08	0·80	11 9
5° E. ...	10·0	6·38	54 39	„ 19	16·38	3·62	0·85	11 48
6° E. ...	9·82	6·65	55 55	„ 18	16·47	3·17	0·95	12 35
7° E. ...	9·56	6·87	57 50	„ 16	16·43	2·69	0·88	15 58
8° E. ...	9·47	7·38	64 43	„ 9	16·85	2·09	0·95	20 58
				1882.				
1° E. ...	10·10	4·51	58° 53′	February 15	14·61	5·59	0·85	10° 7′
2° E. ...	10·35	4·63	56 54	„ 17	14·98	5·72	0·69	1 39
3° E. ...	10·72	4·90	56 49	„ 17	15·62	5·82	0·58	7 52
4° E. ...	11·04	5·22	59 22	„ 15	16·26	5·82	0·55	7 15
5° E. ...	11·21	5·49	62 47	„ 11	16·70	5·72	0·59	10 44
6° E. ...	11·08	5·75	66 31	„ 7	16·83	5·33	0·77	20 34
7° E. ...	10·86	6·28	69 6	„ 5	17·14	4·58	0·82	15 33
8° E. ...	10·55	7·09	74 43	January 30	17·64	3·46	0·83	19 6
				Means*: January 1877—September 1883.				
1° E. ...	9·57	4·76	57° 13′	February 17	14·33	4·81	0·50	25° 36′
2° E. ...	9·88	4·93	54 30	„ 19	14·81	4·95	0·49	39 13
3° E. ...	10·21	5·32	53 57	„ 20	15·53	4·89	0·50	37 12
4° E. ...	10·44	5·75	54 10	„ 20	16·19	4·69	0·51	36 35
5° E. ...	10·56	6·14	55 33	„ 18	16·70	4·42	0·59	36 5
6° E. ...	10·29	6·41	58 12	„ 16	16·70	3·88	0·69	38 31
7° E. ...	10·10	6·83	61 14	„ 13	16·93	3·27	0·81	34 28
8° E. ...	9·96	7·35	64 25	„ 10	17·31	2·61	0·76	48 45
Mean ...	10·13	5·94	57 24	„ 17	16·06	4·19	0·61	37 3

* The above Table and Table IV. have been re-calculated from the mean temperatures of the seven years, and differ somewhat from the arithmetic mean of the co-efficients given above for the separate years, owing to the summation of small differences.

TABLE IV.

HARMONIC CONSTANTS FOR MEAN SEA-TEMPERATURES ALONG THE WHOLE ROUTE, FROM HULL TO HAMBURG, 1877–1883.

—	A_0.	A_1.	e_1.		Approximate date of Minimum.	Mean Maximum.	Mean Minimum.	A_2.	e_2.	
			°	'					°	'
1877 ...	10·35	5·50	56	26	February 18	15·85	4·85	0·85	40	36
1878 ...	10·75	5·37	67	47	" 6	16·12	5·38	0·67	6	24
1879 ...	8·98	6·54	53	28	" 21	15·52	2·44	0·36	27	40
1880 ...	10·28	6·57	58	7	" 16	16·85	3·71	0·61	11	19
1881 ...	9·63	6·01	57	29	" 17	15·64	3·62	0·84	88	0
1882 ...	10·74	5·45	63	0	" 11	16·19	5·29	0·70	9	4
1883* ...	10·09	5·65	57	43	" 16	15·74	4·44	0·69	45	35

* October 1882—October 1883.

TABLE V.

HULL TO HAMBURG. SURFACE-TEMPERATURES, 1877–1883.

Difference between the Monthly Means from Observation and the Monthly Means calculated from the Annual Sine-curve, the latter being subtracted from the former.

Longitude E. ...	1°	2°	3°	4°	5°	6°	7°	8°	Mean.
January	0·16	0·16	0·21	0·27	0·27	0·42	0·55	0·51	0·33
February	0·80	0·62	0·77	0·74	0·69	0·77	0·96	0·95	0·79
March	0·24	0·09	0·21	0·28	0·18	0·24	0·12	0·17	0·20
April	−0·51	−0·68	−0·54	−0·56	−0·67	−0·43	−0·45	−0·30	−0·50
May	−0·94	−0·66	−0·66	−0·60	−0·20	−0·76	−0·73	−0·46	−0·64
June	0·18	0·10	0·29	0·26	0·01	0·08	−0·16	−0·50	−0·13
July	−0·10	0·10	0·16	0·17	0·11	0·44	0·32	0·49	0·21
August	0·32	0·41	0·22	0·21	0·21	0·57	0·59	0·43	0·38
September	0·56	0·60	0.35	0·33	0·40	0·29	0·68	0·38	0·45
October	−0·30	−0·31	−0·24	−0·20	−0·37	−0·41	−0·49	−1·06	−0·42
November	−0·05	−0·25	−0·37	−0·44	−0·59	−0·71	−0·63	−1·08	−0·53
December	−0·51	−0·13	−0·42	−0·47	−0·40	−0·35	−0·38	−0·38	−0·39

TABLE VI.

DIFFERENCES BETWEEN MONTHLY MEAN TEMPERATURES FROM OBSERVATION AND MEANS CALCULATED FROM THE ANNUAL SINE-CURVE.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
1. Falmouth. Sea-temperature (1872–1885). $f(t) = 11{\cdot}7° - 3{\cdot}44 \sin(2\theta + 56°) + 0{\cdot}31 \sin(2\theta + 6°)$.												
Observed ...	8·9	8·6	8·8	9·6	11·1	13·1	14·4	15·4	15·0	13·7	11·6	9·8
Calculated ...	8·9	8·3	8·6	9·8	11·4	13·2	14·5	15·1	14·8	13·6	11·9	10·2
Difference ...	0·0	0·0	0·2	−0·2	−0·3	−0·1	−0·1	0·3	0·2	0·1	−0·3	−0·4
2. Outer Dowsing Lightship. Sea-temperature (1880–1897). $f(t) = 9{\cdot}17° - 4{\cdot}73 \sin(2\theta + 54°) + 0{\cdot}32 \sin(2\theta + 40°)$.												
Observed ...	5·3	4·9	5·0	6·2	7·9	11·4	13·1	14·0	13·7	11·8	9·3	7·3
Calculated ...	5·3	4·4	4·8	6·4	8·6	11·1	13·0	13·9	13·5	12·0	9·7	7·3
Difference ...	0·0	0·5	0·2	−0·2	−0·7	0·3	0·1	0·1	0·2	−0·2	−0·4	0·0

TABLE VI—*continued.*

DIFFERENCES BETWEEN MONTHLY MEAN TEMPERATURES FROM OBSERVATION AND MEANS CALCULATED FROM THE ANNUAL SINE-CURVE—*continued.*

3. Atlantic Ocean, S. of Newfoundland, 45° N., 55° W. Mean Sea-temperature.
$f(t) = 7\cdot44° - 6\cdot86 \sin(\theta + 43°) + 1\cdot44 \sin(2\theta + 4°)$.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Observed ...	2·8	1·7	2·2	2·8	3·9	7·2	12·8	15·6	15·0	12·2	7·8	5·0
Calculated ...	2·8	0·9	0·8	2·4	5·4	9·0	12·1	14·0	14·1	12·5	9·4	5·9
Difference ...	0·0	0·8	1·4	0·4	−1·5	−1·8	0·7	1·6	0·9	−0·3	−1·6	−0·9

4. Atlantic Ocean. 40° N., 55° W. Mean Sea-temperature.
$f(t) = 17\cdot64° - 5\cdot52 \sin(\theta + 45°) + 0\cdot56 \sin(2\theta + 55°)$.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Observed ...	13·9	12·2	12·8	13·9	15·0	16·3	22·2	23·9	22·8	20·6	18·3	16·7
Calculated ...	13·7	12·3	12·3	13·7	16·2	19·1	21·5	23·0	23·0	21·5	19·1	16·2
Difference ...	0·2	−0·1	0·5	0·2	−1·2	−2·8	0·7	0·9	−0·2	−0·9	−0·8	0·5

5. Atlantic Ocean, near to Azores. 40° N., 30° W. Mean Sea-temperature.
$f(t) = 17\cdot59° - 3\cdot27 \sin(\theta + 54° 45') + 0\cdot7 \sin(2\theta + 23° 30')$.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Observed ...	15·0	15·0	15·0	15·6	16·7	18·3	20·6	21·7	21·1	18·9	17·2	16·1
Calculated ...	14·9	14·3	14·6	15·7	17·3	19·0	20·3	20·8	20·6	19·5	17·9	16·2
Difference ...	0·1	0·7	0·4	−0·1	−0·6	−0·7	0·3	0·9	0·5	−0·6	−0·7	−0·1

6. Atlantic Ocean. 30° N., 50° W. Mean Sea-temperature.
$f(t) = 23\cdot0° - 3\cdot5 \sin(\theta + 48°) + 0\cdot74 \sin(2\theta + 49°)$.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Observed ...	20·6	20·0	20·0	20·6	21·1	23·9	26·1	27·2	26·7	23·9	23·3	22·2
Calculated ...	20·4	19·6	19·7	20·6	22·2	24·0	25·5	26·3	26·3	25·3	23·7	21·9
Difference ...	0·2	0·4	0·3	0·0	−1·1	−0·1	0·6	0·9	0·4	−1·4	−0·4	0·3

7. Falmouth. Mean Air-temperature.
$f(t) = 10\cdot98° - 5\cdot82 \sin(\theta + 77°) + 1\cdot21 \sin(2\theta + 60°)$.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Observed ...	6·9	7·0	7·2	9·3	11·6	14·7	16·2	16·2	14·6	11·7	9·1	7·3
Calculated ...	5·3	5·4	7·0	9·7	12·7	15·2	16·7	16·5	15·0	12·3	9·3	6·7
Difference ...	1·6	1·6	0·2	−0·4	−1·1	−0·5	−0·5	−0·3	−0·4	−0·6	−0·2	0·6

8. Greenwich. Mean Air-temperature (1841–1890).
$f(t) = 9\cdot7° - 6\cdot8 \sin(\theta + 83°) + 0\cdot7 \sin(2\theta + 58°)$.

—	Jan.	Feb.	Mar.	Apr.	May.	June.	July.	Aug.	Sept.	Oct.	Nov.	Dec.
Observed ...	3·63	4·17	5·38	8·43	11·72	15·24	16·91	16·45	13·99	10·00	6·23	4·26
Calculated ...	2·95	3·44	5·60	8·94	12·36	15·13	16·45	15·96	13·79	10·46	7·04	4·27
Difference ...	0·68	0·73	−0·22	−0·51	−0·64	0·11	0·46	0·49	0·20	−0·46	−0·81	−0·01