STUPART

BULLETIN OF THE NATIONAL RESEARCH COUNCIL, No. 68, Feb 1929

It is probable that the "few centimeters" of water included a variable number, but this should make little difference in the amount of light transmitted.

Bigelow[9] refers to Shelford and Gail's results as due to the action of the "surface-mirror" by which the light is "reflected or shut out." He concludes that "about 50 per cent of the solar radiation . . . . may be expected to warm" the water (p. 675).

We have not worked on salt water nor have we ever employed the photoelectric cell. We are hardly in a position, therefore, to discuss these results. We mention them in order to state that we have not had similar experiences in our work on inland lakes. There has been no noticeable irregularity or rapid change in the transmission of radiation by surface-water; and the differences between observations on different lakes and on the same lake at different times are such as can be referred to variation in color, plankton, and so forth.

Wisconsin Geological and Natural History Survey

PROBLEMS RELATED TO SURFACE-WATER TEMPERATURE

RELIABILITY OF DIFFERENT METHODS OF TAKING SEA SURFACE-TEMPERATURES

CHARLES F. BROOKS

This paper is published in the Journal of the Washington Academy of Sciences (18: 525-545, Dec. 4, 1928).

OCEAN SURFACE-WATER TEMPERATURES—METHODS OF MEASURING AND PRELIMINARY RESULTS

SIR FREDRIC STUPART, J. PATTERSON, AND H. GRAYSON SMITH

In studying the climatic conditions of America, it appeared that the temperature of the water in the North Pacific might have an important bearing on the development and movements of the high- and low-pressure areas that play the predominate rôle in the character of the weather, especially during the winter season, over a large part of North America, and in 1920 steps were taken to organize the work so that the temperature-data could be collected.

[9] H. B. Bigelow, Physical oceanography of the Gulf of Maine, Bull. Bur. Fish., 40: 511-1027 (1927).

An examination of existing methods at the time showed that there were two different sets of temperatures obtained, one by the officers on deck and the other by the engineers in the engine-room: in the former, the quartermaster by means of a canvas bucket drew up on deck a sample of water and obtained its temperature with an ordinary thermometer uncorrected for instrumental error and generally reading to 2° F: in the latter, the engineer on duty obtained the temperature of the water circulating through some of the pumps with a similar type of thermometer.

Through the cooperation of the Canadian Pacific Ocean Services the sea-water temperature as recorded in the engine-room logs of the vessels in the North Pacific were copied from 1915 and continued until 1926 as a preliminary investigation. The data thus collected were arranged in five-degree quadrangles for each month of the year, and although the readings were subject to considerable error, not only in the thermometers themselves but in the methods of reading them, yet they furnished valuable information as to the prevailing temperatures in the North Pacific.

At the same time that the logs were being copied tests were made as to the best type of thermometer to use, its location and the degree of accuracy required.

As the method with the canvas bucket or of letting water from a faucet pour over the thermometer could not be relied upon to give sufficiently accurate results for scientific purposes, and as the introduction of a new type of thermometer involved extra work for those who had to take the observations, it was essential that the method should not only be reliable but should require a minimum of time to take an observation. The only way to obtain this accuracy and reliability was to leave the thermometer permanently in a well that was always at the temperature of the sea-water, so that the thermometer could be read at any time without having to wait for it to become steady. Such a well could be obtained by inserting a pipe in the intake to the condensers just inside the main valve, or by putting a block of copper with a hole in it for the insertion of the thermometer against the side of the ship and lagging it well so as to fully protect it from the temperature of the room. The simplest and easiest place is of course the intake; but the intake is from 20 to 30 feet below the water-line in modern vessels and it was not known then whether there would be sufficient mixing to that depth to give a fairly accurate temperature of the surface-water. A well on the inside wall of the ship could easily be placed at any depth below the surface, and Waidner, Dickinson, and Crowe[1] while investigating the temperatures in the vicinity of icebergs in 1912 found that the inside wall of the vessel gave

[1] Bull. Bur. Stand., 10: 267 (1914).

the water-temperatures at that point provided the thermometer was sufficiently insulated from the temperature of the room.

Over the greater part of the North Pacific the sea-water temperatures are fairly constant and probably never vary more than two or three degrees from the normal; a variation of five degrees would be very great. Thus a thermometer reading to only 2° F, as is the case of the ship thermometers, would be utterly useless for meteorological purposes so that it was considered advisable to obtain instruments that could be read to 0°.2 F.

As for the type of thermometer it was obvious on account of the ease with which inaccurate readings can be obtained with an ordinary thermometer, and the difficulty of reading it if it is placed in a well in the intake, that some kind of indicating or distance-thermometer would have to be used if reliable observations were to be obtained. Two types were investigated, the resistance-thermometer and the distance-thermograph.

For the first, a device similar to a Whipple indicator with a platinum thermometer was used; and by having it graduated in degrees it was possible to read the temperature directly to 0°.2 F by merely pressing a button and turning the dial which moved the slide along the bridge-wire until a balance was obtained. The platinum wire was wound on a bobbin which was heavily insulated and put in a brass tube: in the final form the lead- and compensation-wires were connected through a lead-covered cable to the indicator so that there was no danger of the insulation breaking down, because of salt water getting on it. The indicator was securely fastened on a shelf on the wall of the vessel a short distance from the thermometer. The brass tube fitted closely into an iron pipe which was inserted in the intake to the condenser.

Although the instrument was simple to operate and could be read quickly, yet a great many difficulties especially with insulation had to be overcome before consistent readings could be obtained.

Two of these instruments were made up and were used to see if it was possible to place the well on the side of the vessel instead of at the intake, by taking comparative readings of the thermometers at approximately the same level. It is a simple matter to have a platinum thermometer wound on a thin disk and placed against the wall of the vessel as was done by Waidner, Dickinson, and Crowe, yet this could not be done with a thermograph-bulb; consequently, one of the platinum thermometers was placed in a well, as shown in Fig. 1. The copper block was about 1½" square with a hole drilled, as shown, to take the thermometer. The face of the copper was placed flush and soldered to a lead sheet which was screwed to the face of the iron castings. The casting was made to

fit between two ribs of the ship and was about 16" by 12" by 3" inside. The box was filled with mineral wool for insulation and made water-tight so that the wool would not get damp. This box was securely fastened to the side of the ship with the copper block pressed hard against the wall and the edges cemented so as to insulate the box as well as possible from the engine-room temperature. There was, however, unmistakable evidence that the thermometer was affected by the temperature of the engine-room.

Facilities were not available at the time to pursue this investigation any further and in the meantime Dr. Brooks[2] had shown that the temperature obtained at the intake gave quite accurately the surface-temperature as obtained from the first six or eight inches below the surface. The observations of Harvey,[3] however, on the temperature at the surface would indicate that at the first opportunity this point should be carefully investigated. Although it was merely a matter of pressing a key and turning a dial until the galvanometer showed no deflection, yet the engi-

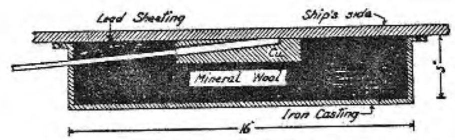

Fig. 1—Well containing platinum thermometer.

neer on duty had to take the observations when he could find the time and it necessitated extra work. Moreover, the instrument was difficult to keep in order and was not a success in the conditions under which it had to be worked.

The second type of instrument was the distance-thermograph from which a continuous record of the temperature was obtained. In trying out this method and getting the range, a mercury-in-steel thermograph with a wall-type recorder having a range of 100° F was installed through the cooperation of the Canadian Pacific Ocean Service on one of their boats plying between Vancouver and Hong Kong. The bulb which was heavily plated with copper was inserted directly in the intake of the condenser but the copper plating was not sufficient to prevent electrolytic action ruining the bulb. The life of the thermograph, though brief, was long enough to demonstrate its superiority over other methods and it was permanently adopted as the standard instrument for obtaining sea-water temperatures; another advantage is that the engineers desire to have

[2] Mon. Weath. Rev., 54: 241-254 (1926).
[3] J. Mar. Biol. Assn. United Kingdom, 13: 683-687.

them. The final method of installing the bulb in the intake is shown in Fig. 2.

The well containing the bulb, consists of a copper pipe having an inch-standard-pipe thread so that it can be very easily inserted into the intake. The bulb is then put into the well and secured with the nuts and packing shown in Fig. 2. There is, however, the possibility of water used about the engine room getting into the openings at *A*, *B*, or *C*, thus in time destroying the capillary; but this can be prevented by filling the openings with good cement.

The recording part which is of the usual thermograph-pattern is simply fastened securely to a shelf, between two of the ribs of the boat where it is in a safe place, and out of the way but easily accessible. It is so placed that about 10 or 15 feet of capillary is sufficient. The trace has never shown any effect of the vibration of the boat. The charts have to be of the best quality, otherwise the constantly high humidity in the

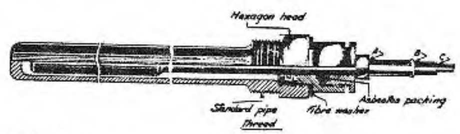

FIG. 2—Method of installing thermograph-bulb in the intake.

engine-room will cause the ink to run. One batch of charts had to be rejected on this account.

It was found that the temperature in the North Pacific on the steamer lanes was between 35° and 85° and the thermographs were obtained with this range. As the work extended, however, some of the vessels traversed regions that had a range from 40° to 90° and others from 30° to 85° or more. As these regions include the North Pacific and the equatorial waters of the Pacific and the West Indies it would appear that practically all ocean-temperatures likely to be obtained would come within the limits of 30° and 90° and this range of 60° has been finally adopted as the standard in the Canadian Service.

THERMOGRAPH OBSERVATIONS UP TO 1927

In Fig. 3 the heavy black lines marked by arrows show the routes actually followed by the different vessels on which thermographs have been installed. On the Northern Pacific route from Vancouver to Yokohama and Hongkong, thermographs have been in use for five years on the SS "Empress of Russia" and for the greater part of that time on the

SS "Empress of Asia" and "Empress of Canada"—all of the Canadian Pacific Ocean Services. More recently a thermograph has been installed on the SS "Aorangi" of the Canadian Australasian Line on the route from Vancouver to Auckland and Sydney. On the Atlantic, ocean-thermographs have been installed on the SS "Canadian Fisher" and

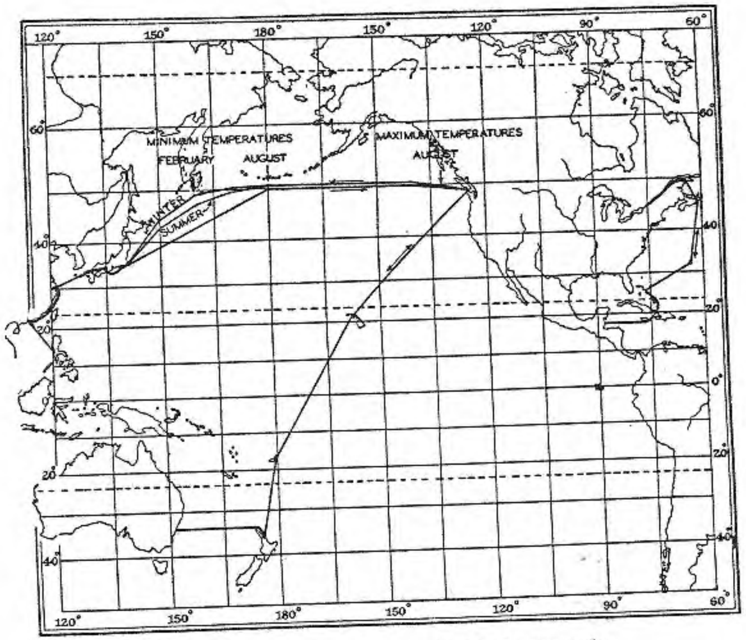

FIG. 3—Routes of vessels equipped with thermographs.

"Canadian Forester" of the Canadian Government Merchant Marine on the route from Montreal or Halifax to Bermuda and the West Indies. On these latter ships, owing to the fact that the temperature-change at the boundary of the Gulf Stream is large and sudden, the thermographs have been equipped with daily instead of weekly charts. Preliminary results indicating the general features of the temperature-distribution are all that have been obtained as yet along the last two routes.

Central Pacific.—Figure 4 shows the average temperatures over five-degree quadrangles for two voyages between Vancouver and Auckland, as an indication of the general temperature-distribution along this route. In order to eliminate to some extent the effect of seasonal variation during the time of the voyage, the figures plotted are the averages of the southbound and northbound trips. A decided fall of temperature at the equator itself is very noticeable, and is a feature which will require examination when sufficient records are obtained.

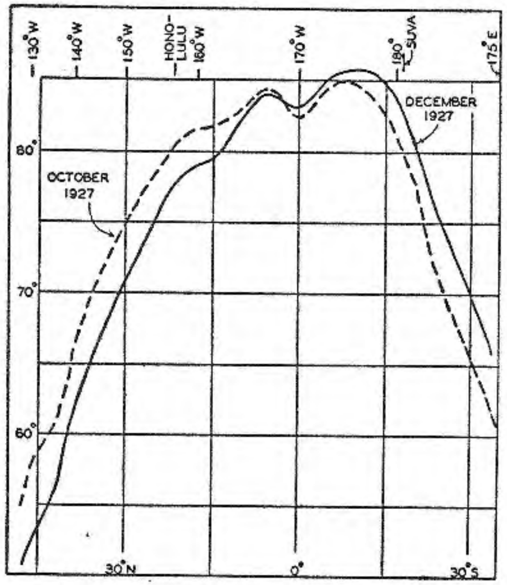

FIG. 4—Average water-temperatures over five-degree quadrangles between Vancouver and Auckland.

Northwest Atlantic and Gulf Stream.—The primary object in obtaining records on ships on the route from Canada to the West Indies is to find the variation in the boundary of the Gulf Stream, and therefore the records from the area between Nova Scotia and Bermuda have been plotted in half-degree quadrangles. Figure 5 shows the record of one voyage along this route, and is given here as an example of the results expected. On the return voyage in this case a very marked discontinuity of temperature was found as the Gulf Stream was left behind, the original record showing a drop of 13° F in five miles.

North Pacific.—The records for the North Pacific from 1923-1927 have been averaged for each five-degree quadrangle from longitude 124° west to 142°.5 east, using the quadrangles from 127°.5 to 132°.5, etc., so that position 125° west and 50° north is the center of the first. This division of the quadrangles is particularly advantageous in this particular case, since for the greater part of the journey from Vancouver to Yokohama, the route lies close to the 50th parallel of latitude. These records have been tabulated by weeks, using the division of the year into 52 weeks as suggested by McEwen, giving a definite observation for about every second or third week for the greater part of the five years. Then smoothed weekly normals have been formed and used for drawing normal curves and curves of departures from normal. This method of tabulation has proved very satisfactory for the region east of longitude 170° east, where the variations are comparatively slow both in longitude and in time. In the warm water nearer to the Japanese coast, however, where large varia-

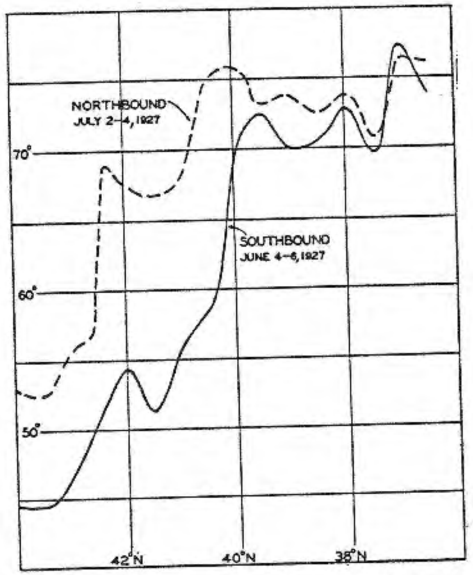

FIG. 5—Water-temperatures obtained in voyage between Nova Scotia and Bermuda.

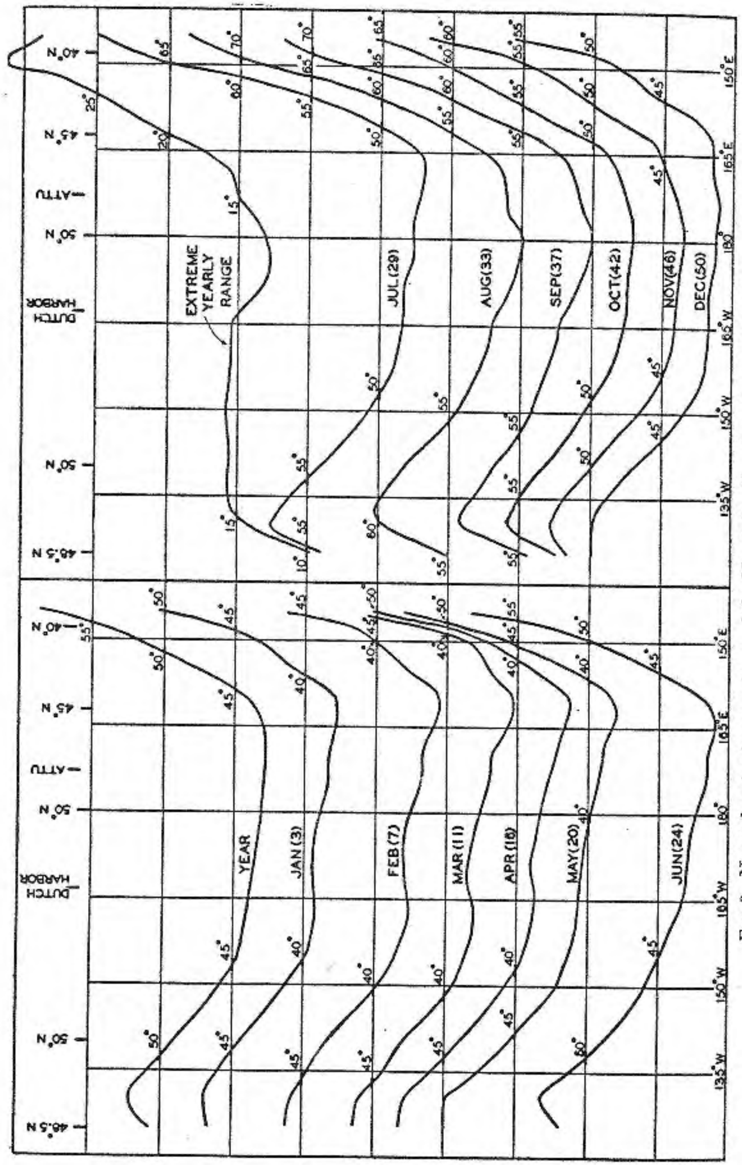

Fig. 6—Normal water-temperatures of the North Pacific, plotted against longitude.

tions are found, it would be better to use smaller areas if a special study of this region were contemplated. The results obtained in this region are further complicated by the considerable difference in the eastbound and westbound routes followed by the steamers. Nothing has as yet been done with the records taken between Yokohama and Hongkong.

Figure 6 shows the normal temperatures of the water of the North Pacific plotted against the longitude, using for this purpose the average of the results of the eastbound and westbound journeys wherever they fall in different quadrangles. The curves are plotted for the middle week of each month, for the yearly average, and for the average yearly range. The cold current off the North American coast described by McEwen [4] is

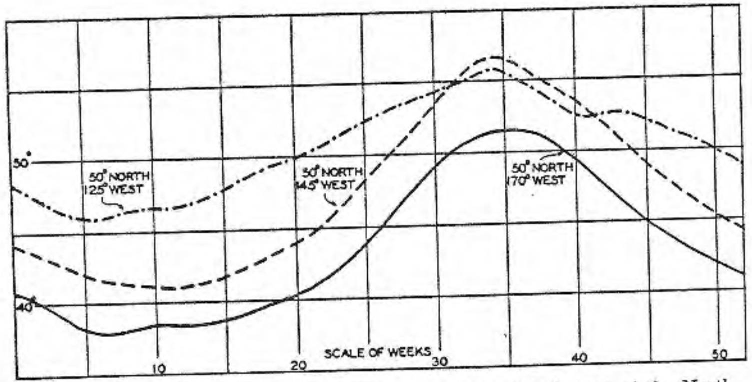

Fig. 7—Yearly water-temperature variations in three typical areas of the North Pacific.

clearly shown in summer, but not in winter. At latitude 50° north, in August its effect is felt as far as five degrees of longitude from the coast. In summer, also, the warm current off Japan is more effective than in winter, displacing the point of minimum temperature from 160° east in winter to 180° in summer, and at the same time increasing the temperature-gradient in the water on both sides of the Pacific.

Figure 7 shows the yearly variations in three typical areas. These show very distinctly a secondary maximum of temperature occurring in the water along the coast about the 43d week (end of October). A secondary minimum is also found in the coast water about the 11th week (middle of March) and a little later farther out. The secondary minimum is evidently due to the appearance of the cool seasonal current along the

[4] G. F. McEwen, Bull. Nat. Res. Counc., no. 61: 222-235 (1927).

coast, and the 43d week maximum to the suppression of this current, allowing the warm water of the easterly current to approach the shore. McEwen considers this current as mainly caused by the prevailing winds, and it is therefore interesting to notice that the average duration of the southwesterly winds which prevail at Victoria in summer is from the 11th to the 39th weeks.

A similar secondary minimum is found in the water off the Aleutian Islands about the 15th week (middle of April). The observations of ocean currents are less complete in this region, but it seems likely that here also the effect is due to a seasonal change in the current distribution.

VARIATIONS OF TEMPERATURE

A study has been made of the departures from normal of the temperatures along the North Pacific route with a view to seeing if any correlation can be found between the variations in the water-temperatures and the weather of Western Canada. As little progress was made in correlating the pressure-distribution with the ocean-temperatures, attention was turned to the departures from normal at selected weather stations along the American coast from North Head to St. Paul Island, and at stations in the interior of Western Canada and Alaska. This comparative study has been made so far for the four years from 1923-1926, and has yielded certain results which may be regarded as preliminary, and which will require further investigation as more observations of ocean-temperatures are received.

As to the slow variation from year to year, there appears to be a fairly definite correlation, especially in winter, between the temperature-gradient in the water and the intensity of the Aleutian low, as shown by the pressure at Dutch Harbour. When the temperature-gradient is large for the time of year, the pressure at Dutch Harbour is low. This, however, does not apply to the regular seasonal changes, since in summer, when the temperature-gradient in the water has its normal maximum, the Aleutian low is inactive, so that other factors must be involved.

As has been noticed before, a failure of the Aleutian low to operate with its usual intensity over an extended period in winter results in a cold season in the Canadian West, and we find therefore a correlation between the temperature-gradient in the water and the temperature at Calgary. When the temperature-gradient is low (cool water along the coast or warm water off the Aleutian Islands) a cold winter is experienced in the Canadian West (but not necessarily in Alaska).

Table 1 shows the mean ocean-temperature (from 124° west to 172°5 east), the mean fall of temperature over the same region, the mean

pressure at Dutch Harbour, and the mean temperature at Calgary, averaged for three-month periods. As far as this table goes, the correlation between the pressure at Dutch Harbour and the temperature-gradient is quite evident in winter and autumn, but apparently disappears to a great extent in summer.

In addition to this effect, as might be expected, the water apparently shares to a certain extent in the general variation of atmospheric conditions. A season of irregular weather on land is accompanied by a season

TABLE 1

Season	Year	Mean sea-temperature	Temperature-gradient	Pressure at Dutch Harbor	Temperature at Calgary
		°F	°F	in	°F
Winter	1923	38.9	6.8	29.74	20.0
	1924	40.9	10.2	29.56	22.5
	1925	41.2	9.4	29.55	19.0
	1926	43.1	12.1	29.13	30.5
Spring	1923	45.5	11.0	29.64	49.5
	1924	44.1	11.2	29.84	48.5
	1925	44.3	11.4	29.73	51.0
	1926	46.3	12.4	29.74	50.0
Summer	1923	52.7	13.2	29.85	59.0
	1924	52.5	10.7	29.84	59.0
	1925	53.4	10.0	29.83	56.5
	1926	55.0	9.0	29.88	54.5
Autumn	1923	46.5	10.9	29.45	34.0
	1924	46.2	8.6	29.73	26.5
	1925	48.4	10.7	29.46	31.5
	1926	49.6	9.6	29.45	28.5

of comparatively rapid and large fluctuations in the temperature of the water (for example, during the greater part of 1924). A generally warm (or cold) season over the whole of Northwestern America is accompanied by generally high temperature in the water. At the same time large warm or cold waves on land frequently appear in the water as well.

Unfortunately, it is still impossible to say which is cause and which effect, or whether both are not controlled by some other factor. During the four years under consideration, in only one instance have conditions changed with sufficient rapidity to permit of deciding which occurred first, the change in water-temperature or the change in the type of weather. The winter of 1923 was a period of very low water-temperature and low gradient, with high pressure at Dutch Harbour and low temperature in British Columbia and Alberta. Then the water-temperature rose quite rapidly between the 10th and 13th weeks throughout the region from the American coast to the Aleutian Islands. The corresponding drop in pressure at Dutch Harbour took place between the 11th and 14th weeks, the temperature rise along the coast about the same time, and at Calgary about one week later. In this one case the change appears to have taken place in the water before it took place in the atmosphere, but before any rule can be laid down regarding this point many more observations of the ocean-temperatures will be necessary.

During the five years that these records have been obtained in the North Pacific there has been a progressive general rise in the temperature of the water, indicating the existence of a change with a period of several years, with some indication that a maximum occurred about the end of 1926. It cannot be said yet what influence this has upon the weather until accurate records are obtained covering at least a complete cycle, although there is some indication that the pressure at Dutch Harbour decreases with a general increase in the water-temperature, as well as with an increase in the temperature-gradient. The whole question is still undecided, and will have to be reexamined after a few more years of ocean-temperature records have been obtained.

Some connection between ocean-temperature and weather can also be traced in the more rapid fluctuations (with periods of one to three months). In a number of cases a period of a month or so of abnormally cold or warm water is accompanied by a similar period of low or high temperature on land. Out of eighteen such cases, in eleven the minimum (or maximum) temperature occurred on land before it occurred in the water; in seven cases, it appeared first in the water. The connection in this case must be indirect, and probably both the water- and air-temperatures are here affected by temporary changes in the prevailing winds.

A curious feature of the one-to-three-month period fluctuations in the water is that apparently no regularity obtains in the order in which they appear in different parts of the ocean. The maximum or minimum seems to be just as likely to occur off the American coast some two weeks before it is evident in the Aleutian Islands as it is to appear first in the West; so that sometimes the curves of departures from normal look as if there were a cold or warm wave spreading from east to west. At other times the fluctuations in the water occur simultaneously over the whole region, and this may be either before or after the corresponding land fluctuation in Southern Alaska.

Meteorological Office,
Toronto, Canada

SIGNIFICANCE OF WATER-TEMPERATURE MEASUREMENTS NOT MADE EXACTLY AT THE SURFACE

G. F. McEWEN

THE TIME REQUIRED FOR TEMPERATURE-DEPARTURES TO CROSS FROM THE WESTERN TO THE EASTERN SIDE OF THE PACIFIC, AND CHANGES IN DEPARTURES DURING THE CROSSING

G. F. McEWEN

The above two papers are published in the Journal of the Washington Academy of Sciences (18: 545-548, Dec. 4, 1928).

PROBLEMS RELATED TO ATMOSPHERIC CIRCULATION

THE EFFECT OF SURFACE-WINDS UPON OCEAN-DRIFT

G. W. LITTLEHALES

A CRITICAL REVIEW OF THE WORK OF THE INDIAN METEOROLOGICAL SERVICE IN MONSOON-PREDICTIONS

R. HANSON WEIGHTMAN

THE EFFECT OF OCEAN-CURRENTS ON THE CLIMATE OF CONTINENTS

ALFRED J. HENRY

The above three papers are published in the Journal of the Washington Academy of Sciences (18: 548-558, Dec. 4, 1928).